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DEVELOPMENT OF A TOW CAPABILITY FOR THE HH-3F HELICOPTER

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DEVELOPMENT OF A TOW CAPABILITY FOR THE HH-3F HELICOPTER

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FINAL REPORT

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16. Abstract

An extensive evaluation was conducted to determine the capability of the HH-3F helicopter to tow the Fast Surface Delivery (FSD) System. The aircraft flying qualities, aircraft response to simulated emergencies, Automatic Flight Control System, and the simplicity and reliability of the tow equipment enhance the ability of the HH-3F helicopter to fulfill the requirements of the U. S. Coast Guard tow mission. Mission limitations are imposed by the low power margin at high gross weights in the low speed tow regime. Inefficient transmission oil cooler operation limits the amount of time allowed in a downwind tow condition. Further testing is recommended to determine pilot fatigue limitations due to unusual aircraft attitudes during tow operations. Also, additional testing is necessary to determine the effects of higher sea states on the aircraft and FSD combination. Within the scope of this evaluation, the HH-3F helicopter and FSD tow combination is satisfactory for the U. S. Coast Guard operational tow mission.

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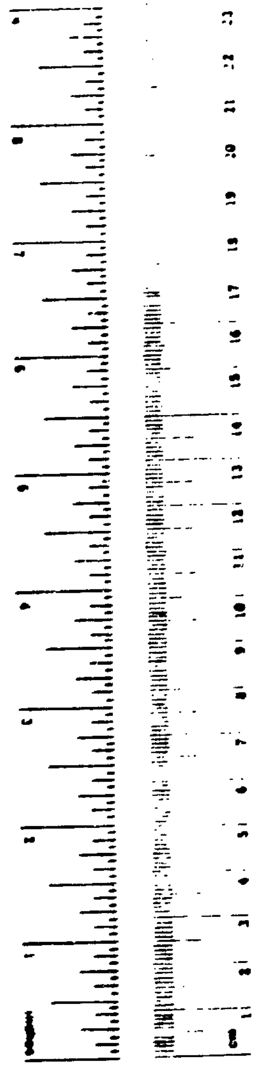
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

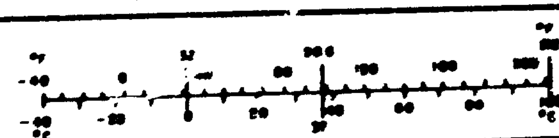


TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

BACKGROUND

1. The U. S. Coast Guard is developing a Fast Surface Delivery (FSD) System to more effectively transport marine pollution equipment to remote oil spill sites. Reference 1 requested the Naval Air Test Center (NAVAIRTESTCEN) to develop a HH-3F helicopter towing capability for this equipment. Prototype tow hardware was designed, fabricated, and installed in an instrumented HH-3F helicopter, CG No. 1471. Static and dynamic tow testing and flight envelope development were conducted at NAVAIRTESTCEN and the U. S. Naval Coastal Systems Laboratory (NAVCOASTSYSLAB), Panama City, Florida. References 2 through 7 summarize interim progress in all program areas. Reference 8 was the interim report on the tow envelope development tests at NAVCOASTSYSLAB.

PURPOSE

2. The purpose of the evaluation was to determine the feasibility of the HH-3F helicopter towing the FSD system and to develop a tow flight envelope.

DESCRIPTION OF EQUIPMENT

3. The test helicopter, HH-3F CG 1471, was a production model specially instrumented for the tow tests. The HH-3F is a twin-engine, utility/search-and-rescue helicopter which has a single, five-bladed, fully articulated main rotor, a five-bladed articulated tail rotor, and retractable tricycle-type landing gear. It is powered by two General Electric T58-GE-5 engines, each rated at 1,500 SHP at sea level-standard day conditions. A detailed aircraft description is presented in reference 9. A photograph of the helicopter is presented in Appendix A, figure 1.

4. The test aircraft was equipped with prototype tow hardware consisting primarily of a yoke assembly, a quick release hook, airframe hard points, and a 600-foot tow cable on a drum-type reel. A complete description of the prototype equipment and design analysis is presented in Appendix B. Photographs of the installation are presented in Appendix A, figures 2 and 3. Detailed engineering drawings of the hardware will be forwarded separately.

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5. The FSD system is a planing hull sled designed and fabricated by NAVCOASTSYSLAB to deliver oil pollution control equipment to oil spill sites. The FSD sled has an empty weight of 10,200 pounds and was designed to carry a 17,000 pound payload. In addition to the empty sled, three payloads -- the Air Deliverable Antipollution Transfer System (ADAPTS), the High Sea Oil Barrier, and the High Sea Oil Recovery Device -- were towed during the evaluation. The FSD is 45-feet long, 15-feet wide, and 9-feet high at the bow. A complete description of the FSD is contained in reference 10. Gross weight and cg location for each configuration towed are presented in Appendix C, table I. Photographs of each configuration are presented in Appendix A, figures 4 through 7.

SCOPE OF TESTS

6. Safe flight envelopes were developed for the HH-3F helicopter while towing the FSD sled in four configurations and while conducting static tow. Dynamic tow was conducted under daylight visual meteorological conditions (VMC) in seas of maximum significant wave height 3 to 5 feet. Flying qualities and performance characteristics of the HH-3F during static and dynamic tow operations were evaluated in 28 flights (40 flight hours) under the conditions shown in Appendix C, tables II and III. Loading for all flights was for the normal utility mission and included two pilots and two crewmen. Maximum takeoff weight was 19,000 pounds. Weight and balance information is presented in Appendix D. Average cg location was approximately mid-range and was comparable to normal mission cg. The Automatic Flight Control System (AFCS) was on for all tests, and the altitude coupler was engaged. All cockpit-controlled bleed air devices were off throughout the tests. Electromagnetic Compatibility (EMC) testing was conducted in the Interference Test Laboratory, a shielded hangar facility, at NAVAIRTESTCEN. Normal aircraft operating limitations published in reference 9 were observed and are summarized in Appendix C, table IV, and Appendix E, figure 1.

7. Avionics bench tests were performed to assure all equipment operated within specifications. Avionics equipment limitations were determined for Electromagnetic Interference (EMI) generated by the tow installation.

METHOD OF TESTS

8. A gradual buildup to critical envelope limits was conducted to develop the flight envelope. Envelope limits were defined by inadequate power margin, excessive pitch and/or roll attitudes, or wave height and direction. Aircraft response to wind gusts or inadvertent control inputs was simulated at incrementally increasing tow cable tensions by pulse and doublet inputs in all four axes. Single-engine failures under static tow conditions were simulated by rapidly retarding an engine speed selector to the ground idle position. Single axis AFCS hardovers under tow were induced through the AFCS channel monitor panel. A chase helicopter was utilized for all envelope development flights, and motion picture coverage was provided for the postflight analysis. Handling qualities ratings (HQR's) were assigned in accordance with the Cooper Harper Scale (Appendix C, table V) as published in reference 11.

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9. The EMC tests were conducted under controlled electromagnetic conditions as follows:

a. The aircraft was placed in a cleared area within the EMC test laboratory with wheels down and locked and rotor blades in the extended position.

b. No objects (metallic or nonmetallic) were placed within 40 feet of the aircraft, except for test antennas and/or test equipment.

c. All laboratory screens, personnel entrance doors, and aircraft hatches were closed during tests in order to maintain the shielding integrity of the laboratory and the aircraft and to simulate flight electromagnetic environment conditions.

10. Each electronic system was operated over its frequency band as a potential source of EMI to the tow installation and other aircraft systems.

11. All electrical switches, circuit breakers, and rotatable controls/switches were exercised several times as a potential source of EMI to the tow installation or other aircraft systems.

12. Flight tests were conducted to validate EMI encountered during laboratory EMC tests and to test for EMC problems peculiar to the airborne configuration.

13. An airborne analog magnetic tape recording system was used to record flight parameters. Telemetry to a ground data processing station was also provided. Data reduction was performed automatically by computer in real-time with the Real-Time Telemetry Processing System (RTPS) for all tests conducted at NAVAIRTESTCEN. For tests conducted at NAVCOASTSYSLAB, data were received by a portable telemetry station and reduced manually from analog strip charts. Vibration data were reduced at NAVAIRTESTCEN from airborne tape-recorded data. All data analysis was performed by project personnel. Sample aircraft performance calculations are contained in Appendix F. Several parameters, including cockpit control positions, tail rotor blade pitch angle, tow cable tension, and skew angle, were also displayed in the cockpit for pilot reference. Pilot's qualitative comments were recorded on a tape recorder and on kneeboard data cards. A complete list of airborne instrumentation is presented in Appendix C, table VI. The aircraft cockpit instrumentation is illustrated in Appendix A, figures 8 and 9.

CHRONOLOGY

14. The chronology of the program was as follows:

a.	Work statement received	21 October 1974
b.	Military Interdepartmental Procurement Request received	7 January 1975
c.	Task I (tow hardware design) commenced	9 January 1975
d.	Task III (prepare HH-3F for flight tests) commenced with instrumentation	9 January 1975
e.	Project aircraft arrived at NAVAIRTESTCEN	19 February 1975
f.	NAVAIRTESTCEN pilot HH-3F simulator training	10-14 March 1975
g.	Task I completed	31 March 1975
h.	Task II (fabrication of tow hardware) commenced	1 April 1975
i.	Task II completed	31 May 1975
j.	Task III completed	11 July 1975
k.	Task IV (flight tests)	14 July - 22 August 1975
l.	Task V (NAVCOASTSYSLAB tests)	15-30 September 1975
m.	Test instrumentation removed	15 October 1975
n.	Aircraft returned to AR&SC, Elizabeth City, North Carolina	17 October 1975

RESULTS AND DISCUSSION

GROUND TESTS

BONDING

15. Bonding resistance between the tow modification and the basic airframe was measured at several points using the Electronics Instruments Limited Milliohmmeter, Model 47A, S/N 47356A. All measurements exceeded the limits specified in reference 12 except the electrical release on the boom. Since there were no specified bonding requirements in the tow modification, there were no further attempts to reduce the bonding resistance. The bonding resistance of the various tow components is presented in Appendix C, table VII. Bonding specifications should be developed for the tow modification and measurements should be conducted to ensure compliance with these specifications.

EMC TESTS

General

16. The EMC tests were divided into ground tests conducted in the EMC test laboratory and flight tests conducted at the static tow rig. High frequency (HF) and very high frequency (VHF) transmissions in the laboratory caused tow cable releases; however, in flight, there were no releases due to HF or VHF transmissions. The HH-3F avionics equipment does not cause any significant EMI problems with the tow modification kit.

AN/ARC-94

17. The HF radio transmitter was operated in the 3 to 27 MHz frequency range. Transmissions in the frequency range of 5.610 to 5.810 caused tow cable release in the laboratory. These frequencies were tested in flight. No tow cable releases were found in flight; however, EMI associated tensiometer fluctuations of ±1,000 pounds resulted from 5.696 and 6.0 MHz transmissions.

AN/ARC-84

18. The VHF-AM radio transmitter EMI caused the tow cable to be released in a frequency range of 134.9 to 135.95 MHz under laboratory conditions. The releases occurred when the tensiometer fluctuations exceeded 12,000 pounds and actuated the automatic release feature. The above frequency range was tested in flight, and no inadvertent tow cable releases occurred. Tensiometer fluctuations of ±1,000 pounds occurred in this frequency range.

AN/ARC-51A

19. The UHF radio transmitter was tested in a frequency range of 225 to 358 MHz. No tow cable releases occurred, and no significant tensiometer fluctuations were noted in the laboratory or in flight.

TOW HARDWARE INSTALLATION/REMOVAL

20. An evaluation of tow equipment installation and removal was conducted by the aircraft aircrewmen. Standard tool box items were used by two crewmen. The assumption was made that permanently installed hardware would include airframe hard points for mounting the tow yoke, the load sensor electronic box, cockpit indicators and releases, associated electrical wiring, and lifeline. This equipment should be made an integral part of the HH-3F airframe. Equipment considered portable or removable for the evaluation include the tow cable and reel litter, yoke assembly, quick release hook, rewind motor with battery pack, and ramp fairlead. The location of the majority of this equipment is depicted in Appendix A, figures 2 and 3. The removal and installation time for this portable equipment was 1 man-hour in each instance. This time could be shortened by mounting the tow yoke with quick release pins instead of the attaching bolts. Quick release pins should be substituted for the tow yoke attaching bolts.

STATIC TOW

21. The static tow tests were conducted to help identify problems before the dynamic tow phase, to provide an efficient and safe buildup program, and to investigate areas considered too hazardous for dynamic tow. Fifteen data flights were conducted with tow tensions up to 6,000 pounds and wind azimuth from 0-360 degrees. In addition to static tow performance data, single-engine failure under tow and AFCS hardover failures were evaluated. Results of these tests indicated that the HH-3F is power limited as discussed in paragraph 33. The single-engine failure above 75-feet AGL required minimal pilot effort for a successful flyaway (HQR-3). The directional and vertical axes for AFCS hardovers required the most immediate pilot response, but all hardover recoveries were executed with no significant problems (HQR-3).

PERFORMANCE

22. The static tow performance data were used to help predict the power required during the critical low speed portion of the dynamic tow phase. The data are depicted in Appendix E, figure 2. As the aircraft gross weight increases, the power required increases into the military power range; therefore, a 30-minute time limitation is imposed on operations. The most readily available solution was to reduce aircraft gross weight by reducing the fuel load. A fuel load of 3,000 pounds (aircraft gross weight of 18,500 pounds) was selected to simulate fuel necessary for adequate endurance and to allow the conduct of the majority of low speed operations in the continuous power range. Endurance is determined through the performance curves in the HH-3F Flight Manual with the aid of tow performance curves described in paragraphs 33 and 34.

23. Limitations discovered during the static tow operations included a maximum allowable tow tension of 6,000 pounds. The tow equipment is capable of sustaining a tow tension of 12,000 pounds before actuating the automatic tow cable release. The tow tension limit of 6,000 pounds was the point at which the tow cable contacted the aft ramp. Tow cable clearances with the tail pylon and the tail rotor were adequate during all phases of tow operations and are satisfactory for tow operations. A maximum tow tension of 6,000 pounds should be used during tow operations.

24. Aircraft attitude was observed at various tow tensions. Appendix E, figure 3, depicts the roll and pitch attitudes for tow tensions up to 5,500 pounds during static tow. The pitch attitude varied from almost 5-degrees nose up with zero tensions to 10-degrees nose down with 5,500-pounds tow tension during static tow. These attitudes were confirmed during the dynamic tow portion of the test program. The dynamic tow aircraft attitudes are contained in Appendix E, figure 4. At the higher tow tensions, the aircraft nose-down pitch attitude is in excess of 6 degrees. This is uncomfortable to the pilot and would present an operational limitation due to pilot fatigue. Further testing should be conducted to determine pilot fatigue limitations due to unusual aircraft attitudes during tow operations.

SINGLE-ENGINE FAILURES

BUILDUP

25. Single-engine failure testing was conducted during static tow with tensions up to 6,000 pounds. Since the aircraft is actually in a hover regime during static tow, the single-engine failure buildup was conducted in a hover at altitudes from 5 to 75 feet in 5-foot increments. Up to 25 feet, single-engine engine landings were executed at touchdown speeds less than 10 knots. The altitude band of 25-35 feet was the most difficult region with touchdown speeds greater than 10 knots and minimum rotor speed of 84 percent (N_r). Landings from above 40 feet were executed by lowering the nose to gain forward airspeed and reducing collective setting slightly (HQR-4). Flyaways following single-engine engine failures at 75 feet were easily executed (HQR-3).

SINGLE-ENGINE FAILURES UNDER TOW

26. Single-engine failures were simulated under tow by rapidly retarding a single speed selector to the ground idle position. A test altitude of 75 feet was chosen based on the buildup program and cable-to-ramp clearance. The aircraft gross weight was 16,500 pounds, OAT was +30°C, and the wind was 7-10 knots. All tests were conducted into the wind.

27. The primary cockpit cue to an engine failure was the immediate split in engine torques. Airframe responses were negligible in pitch and roll and less than 5 degrees in yaw. The AFCS utilizing the ASN-50 provided excellent heading hold capability. Aural cues, such as engine noise, were not readily discernible in the cockpit and could be completely masked by external or internal communications. An artificial RPM warning system should be incorporated in all U. S. Coast Guard H-3 model helicopters in order to provide pilots with an aural warning of engine power loss. Aft crewmembers reported that immediate aural detection of the engine failure was possible at their station. For all single-engine failure cable releases, the aft crewmember mechanical release was initiated prior to the cockpit electrical release. Appendix E, figure 5, depicts a typical single-engine failure under static tow conditions at 3,000-pounds tow tension. As indicated above, airframe response was minimal, and the crew member mechanical release occurred 1.5 seconds after engine failure. Aircraft nose attitude, when towing, facilitates translation to forward flight. As depicted in Appendix E, figure 5, collective and cyclic movements required are minimal after a single-engine failure. Maximum altitude loss was 40 feet (from an altitude of 75 feet) before a positive climb rate was established. It is anticipated that dynamic tow forward airspeed will enhance recovery from a single-engine failure. A minimum of 75-feet AGL is recommended for all static and dynamic tow operations in order to provide a safe single-engine flyaway.

AFCS HARDOVERS

28. Aircraft response to AFCS hardovers was evaluated under static tow conditions at tow cable tensions ranging from 2,000 to 5,000 pounds. Single-axis hardover inputs were initiated by use of the AFCS channel monitor hardover switches. Representative time histories of aircraft response to hardovers in each axis are presented in Appendix E, figures 6 through 9. In each axis, aircraft attitude, rates, and accelerations provided the pilot with an excellent cue to the hardover condition; the "A" mode of the hover indicator confirmed the existence of an AFCS hardover. The aircraft motion due to AFCS hardovers presented no significant problems and recovery was accomplished with minimal pilot effort (HQR-3).

29. The yaw and collective down hardovers required the most immediate pilot response. With the pilot's feet off the rudder pedals, yaw-axis hardovers in either direction resulted in the tow cable contacting the ramp support cables within 2 seconds after the hardover input. The majority of tow operations should be conducted with the pilot's feet on the rudder pedals. Collective channel hardovers in the down direction resulted in altitude losses up to 30 feet. These hardovers were easily overcome, but reemphasize the need for the pilot to fly with his hand on the collective. AFCS hardover failure demonstrations while under static tow should be incorporated in a tow training syllabus.

EMERGENCY RELEASES

30. To enhance flight safety, the towed vehicle can be released mechanically by the crew in the cabin, electrically by the pilot in the cockpit, or automatically at tension of 12,000 pounds. Mechanical and electrical releases were conducted during static tow. These releases were conducted at various skew angles and up to a maximum of 6,000-pounds tow tension. Releases at the left and right skew limits of 15 degrees were conducted. Aircraft response was easily controlled and no damage was observed to either the aircraft or the tow equipment following mechanical and electrical releases at the maximum skew angle. The tow cable mechanical and electrical release mechanisms and aircraft response to these releases are satisfactory for the HH-3F tow mission.

DYNAMIC TOW

GENERAL

31. Tow envelope expansion was conducted at an average gross weight of 19,000 pounds in seas up to significant wave height 3 to 5 feet. Wind velocity was 15 knots or less for all tests. Maximum tow cable tension, sled speed, and tension required for sled hydroplaning are shown in table I.

Table I

Tow Characteristics

Configuration	Weight (lb)	Planing Tension (lb)	Max Tension (lb)	Max Water Speed (kt)
Sled (Empty)	10,200	1,000	5,000	31
Sled and ADAPTS Kit	15,900	2,500	6,000	53
Sled and Barrier	25,500	3,500	6,000	46
Sled and Recovery Device	23,800	3,500	6,000	36

32. In each configuration towed, the sled commenced hydroplaning at approximately 20 knots. Until hydroplaning speed was achieved, helicopter dual-engine torque and engine performance parameters were in the military power 30 minute limit range specified in Appendix C, table IV. After hydroplaning speed was achieved, aircraft power required to tow decreased significantly. The combined effects of reduced hydrodynamic drag and flight in the translational lift region were responsible for reduced power required. Appendix C, tables VIII to X, summarize the HH-3F aircraft tow characteristics, the towed vehicle characteristics, and the maximum continuous power tow characteristics. The HH-3F and FSD tow combination is satisfactory for the Coast Guard operational tow mission up to a sea significant wave height of 3 to 5 feet. Further testing should be conducted in seas greater than significant wave height 3 to 5 feet.

PERFORMANCE

Low Speed

33. Low speed tow performance is the measurement of power required to tow the FSD up to planing speed. Static tow test data were verified under dynamic tow conditions. In the low speed tow range, wind velocity and tow skew angle do not affect the tow performance. Low speed tow performance for several tensions is presented in Appendix E, figures 2 and 10 to 12, as part of the total HH-3F tow performance curves for each configuration. Maximum low speed tow performance is summarized in Appendix E, figure 13, and reveals an aircraft gross weight limitation, particularly when the FSD is loaded. The low speed portion of a tow mission profile takes approximately 10 minutes; therefore, military power should be utilized to obtain sled planing speed. The HH-3F low speed tow power required characteristics are limited at high aircraft gross weights for the Coast Guard tow mission. Military power should be utilized to obtain FSD planing speed at high aircraft gross weights.

High Speed

34. High speed tow performance is the measurement of the power required to tow the FSD after it reaches planing speed. This portion of the evaluation was conducted under dynamic tow conditions while towing the various FSD loadings. The tow and level flight performance profiles are similar, except that tow tension instead of airspeed is plotted as a function of power required as shown in Appendix E, figure 14. Optimum tow performance was defined as existing in the area of minimum power required. The planing tension was established as the intersection of the slow and high speed tow performance curves. This effect can be seen clearly in Appendix E, figures 10 to 12. The effect of aircraft gross weight on planing speed is also shown in Appendix E, figures 10 to 12. The largest deviation in planing speed was approximately 100 pounds of tow tension per 1,000 pounds of aircraft gross weight. The crew cannot easily read this small change in tow tension from the aircraft instruments; therefore, planing speed or tension handbook data will be average values for each specific towed FSD configuration. Maximum high speed tow performance is summarized in Appendix E, figure 15. The high speed tow performance of the HH-3F helicopter is satisfactory for the Coast Guard tow mission.

TOW VIBRATION LEVELS

35. Vibration levels were measured at each engine forward-engine mount and in various airframe positions. The highest vibration levels occurred on the No. 2 engine mount in the longitudinal direction. A maximum of 3.7 g at 422 Hz was measured in a left turn under tow. The maximum allowable vibration level at 422 Hz is approximately 15 g. All other engine mount vibration levels were less than 0.75 g. Typical airframe vibration level measurements were consistently below 0.1 g. The vibration characteristics of the HH-3F under tow are satisfactory for the Coast Guard tow mission.

DOWNWIND TOWING

36. Extended downwind towing operations resulted in a steady increase in main transmission oil temperature. The rate of increase was approximately 3 degrees/minute. Pilot corrective action was to turn into the wind and reduce tow cable tension. Transmission oil temperature immediately decreased to within normal operating range as defined in Appendix C, table IV. Inadequate transmission oil cooler operation during extended downwind towing operations will degrade mission effectiveness by reducing effective tow range. Downwind towing should be kept to a minimum.

FLYING QUALITIES

Gust Response

37. Aircraft response to sudden wind gusts was evaluated by the introduction of sudden control inputs in each axis with the AFCS ON. The aircraft response to control inputs was heavily damped as shown in Appendix E, figures 16 and 17. In each case, the aircraft returned to its original tow attitude within 3.5 seconds after completion of the control inputs. The sled response to control inputs was negligible. The gust response of the HH-3F helicopter during tow operations helps minimize pilot work load and enhances the accomplishment of the tow mission.

Tow Cable Oscillations

38. Moderate to severe tow cable tension oscillations or surging occurred with all sled configurations. Sea direction and wave height combined to produce sled pitching and yawing moments which resulted in this surging phenomenon. The amplitude of these oscillations or tensions surges varied directly with wave height and tow speed and inversely with sled loading. The most severe surging occurred with the empty sled configuration. Surging is a function of tow speed and sea direction -- seas from 135 to 225 degrees relative to aircraft heading caused the most surging. Oscillations were characteristically undamped or divergent. Pilot corrective action was to slowly reduce tow tension with aft cyclic until the surges ceased and the cyclic was then returned to the trim position (HQR-4). Without

immediate pilot corrective action, tensiometer oscillations of 1,500 pounds occurred within 3 to 5 seconds. A hands-off tow using the AFCS coupler was conducted during a 1-mile run. The coupler performed satisfactorily but was unable to adequately react to the surging phenomena. While towing, application of aft cyclic should be used to dampen tow cable oscillations caused by sea condition and direction. In addition to optimum tow performance, the optimum tow tension for each configuration, Appendix C, table VIII, was based on helicopter handling qualities, dynamic sled response, sea conditions, and pilot comfort. Towing with optimum tow tension minimized tow cable oscillations and decreased pilot work load. The tow mission should be conducted at optimum tow tension.

OPERATIONAL TOW TECHNIQUES

39. The tow techniques developed during the test program require prebriefed knowledge of procedures and crew coordination. A summary of tow operating techniques contained in Appendix G is satisfactory for tow operations and should be incorporated in current operating documents. Specific areas of the tow mission that require amplifying information are addressed in the following paragraphs.

APPROACH AND HOOKUP

40. During the approach, downwash from the main rotor caused the FSD to drift which increased the pilot effort to stabilize in position for hookup. To help eliminate sled drift, an approach was commenced to a position downwind of the sled; cable payout was commenced as the aircraft moved toward the sled. As a result, the hookup was in progress prior to the impingement of main rotor downwash on the sled, and sled drift was held to a minimum. During the approach hookup phase, an approach to a position downwind of the sled should be utilized to minimize sled drift.

TENSION TAKE-UP

41. Tension take-up for the FSD required less pilot effort than on the static tow rig. The FSD commenced movement through the water before all slack was taken up. Helicopter response to cable tension was noticeable but not as severe as under static tow conditions. Pilot technique during initial cable take-up was to trim the helicopter for a precise hover and make small inputs against the trim position in order to effect a smooth take-up. After tensiometer indications became reliable, the technique was to utilize the cyclic-mounted beeper trim to make tension changes. During tension take-up, smooth cyclic inputs, coordinated with the aft crewman's voice reports, should be used to prevent adverse aircraft longitudinal surging induced by tow cable oscillations.

TOW FLIGHT

42. Longitudinal AFCS authority was exceeded shortly after tow tension was applied. This increased the pilot effort required to maintain a constant tension. AFCS authority was regained by slowly adjusting the cg trim to bring the AFCS indicator pitch bar back to center. After this adjustment, forward cyclic displacement is required to maintain constant tension. Utilization of the cg trim knob to maintain longitudinal AFCS authority during tow operations is recommended.

43. Tow cable skew angle was easily controlled in maneuvering and non-maneuvering flight. Turn rates were qualitatively assessed in a hover. A turn on the spot was used to determine minimum turn radius to simulate confined area operations. During all these maneuvers, skew response to an input was almost instantaneous. However, all turns should be done slowly to reduce surging and the tendency for pilot induced oscillations (PIO's) when attempting to maintain constant tow tension. In tow cruise, the skew angle should be monitored closely to prevent the tow cable from contacting the ramp extension cables. Skew angle response is satisfactory for the turn rates and radii required for the operational tow mission.

44. A tensiometer and a skewmeter are essential for the tow mission. The instruments used during the evaluation are depicted in Appendix A, figure 8. Both the pilot and copilot should be provided with an instrument that combines skew angle and tow tension in one unit. A flip-up type instrument, similar to the flip-up aircraft checklist, would enable the pilots to secure the instrument for nontow operations.

45. Tow altitudes varied from 75 feet to 100 feet AGL. This altitude band provided a safe, single-engine flyaway altitude, minimized salt spray, and provided adequate cable-to-ramp clearance. Altitude control, using the altitude coupler feature of the AFCS, was excellent and greatly reduced the pilot work load. HH-3F towing operations should not be conducted without a fully functional AFCS and altitude coupler.

TOW RELEASE

46. Tow release operations are the opposite of hookup operations and are presented in Appendix G. Pilot procedures require that the longitudinal trim be returned to the pretakeoff setting following tow operations. In order to provide the pilots with accurate tow cable retrieval information and to facilitate aircrew duties, the last 40 feet of the tow cable from the free end should be color coded.

CONCLUSIONS

GENERAL

47. The HH-3F helicopter can safely tow the FSD system and conduct tow operations within the envelopes presented in this report.

SPECIFIC

48. The HH-3F avionics equipment does not cause any significant EMI problems with the tow modification kit (paragraph 16).

49. The time for the removal and installation of the tow portable equipment could be shortened if quick release pins were utilized instead of the attaching bolts for mounting the tow yoke (paragraph 20).

50. Single-engine failure above 75-feet AGL required minimal pilot effort for a successful flyaway (paragraph 21).

51. The directional and vertical axes for AFCS hardovers required the most immediate pilot response (paragraph 21).

52. The tow cable contacted the aft ramp at 6,000 pounds of tow tension (paragraph 23).

53. Tow cable to tail pylon and tail rotor clearances were adequate during all phases of tow operations (paragraph 23).

54. At the higher tow tensions, aircraft nose-down pitch attitude in excess of 6 degrees is uncomfortable to the pilot (paragraph 24).

55. With the pilot's feet off the rudder pedals, yaw axis hardovers in either direction will result in the tow cable contacting the ramp support cables within 2 seconds (paragraph 29).

56. Collective channel hardovers in the down direction will result in altitude losses up to 30 feet (paragraph 29).

57. The tow cable mechanical and electrical release mechanisms and aircraft response to these releases are satisfactory for the HH-3F tow mission (paragraph 30).

58. The HH-3F and FSD tow combination is satisfactory for the U. S. Coast Guard operational tow mission up to a sea significant wave height of 3 to 5 feet (paragraph 32).

59. The HH-3F low speed tow power required characteristics are limited at high aircraft gross weights for the Coast Guard tow mission (paragraph 33).

60. The high-speed tow performance of the HH-3F helicopter is satisfactory within the scope of this test for the U. S. Coast Guard tow mission (paragraph 34).

61. The vibration characteristics of the HH-3F under tow are satisfactory for the Coast Guard tow mission (paragraph 35).

62. Inadequate transmission oil cooler operation during extended downwind towing operations will degrade mission effectiveness by reducing effective tow range (paragraph 36).

63. The gust response of the HH-3F helicopter during tow operations helps minimize pilot work load (paragraph 37).

64. Towing with optimum tow tension minimized tow cable oscillations (paragraph 38).

65. The summary of tow operating techniques contained in Appendix G is satisfactory for tow operations (paragraph 39).

66. Skew angle response is satisfactory for the turn rates and radii required for the operational tow mission (paragraph 43).

67. A tensiometer and skewmeter are essential for the tow mission (paragraph 44).

68. Altitude control using the altitude coupler feature of the AFCS was excellent (paragraph 45).

RECOMMENDATIONS

69. Bonding specifications should be developed for the tow modification and measurements should be conducted to ensure compliance with these specifications (paragraph 15).

70. The airframe hard points for mounting the tow yoke, the load sensor electronic box, cockpit indicators and releases, associated electrical wiring, and lifeline should be made an integral part of the HH-3F airframe (paragraph 20).

71. Quick release pins should be substituted for the tow yoke attaching bolts (paragraph 20).

72. A maximum of 6,000-pounds tow tension should be used during tow operations (paragraph 23).

73. Further testing should be conducted to determine pilot fatigue limitations due to unusual aircraft attitudes during tow operations (paragraph 24).

74. An artificial RPM warning system should be incorporated in all U. S. Coast Guard H-3 model helicopters (paragraph 27).

75. A minimum of 75-feet AGL should be used during all static and underway dynamic tow operations (paragraph 27).

76. The majority of tow operations should be conducted with the pilot's feet on the rudder pedals (paragraph 29).

77. AFCS hardover failure demonstrations while under static tow should be incorporated in a tow training syllabus (paragraph 29).

78. Further testing should be conducted in seas greater than significant wave height 3 to 5 feet (paragraph 32).

79. Military power should be used to obtain FSD planing speed at high aircraft gross weights (paragraph 33).

80. Downwind towing should be kept to a minimum (paragraph 36).

81. While towing, aft cyclic should be used to dampen tow cable oscillations caused by sea condition and direction (paragraph 38).

82. The tow mission should be conducted at optimum tow tensions (paragraph 38).

83. The summary of tow operating techniques contained in Appendix G should be incorporated in current operating documents (paragraph 39).

84. During the hookup phase, an approach to a position downwind of the sled should be utilized (paragraph 40).

85. During tension take-up, smooth cyclic inputs should be used in coordination with the aft crewman/s voice reports (paragraph 41).

86. The cg trim knob should be utilized to maintain longitudinal AFCS authority during tow operations (paragraph 42).

87. All turns should be done slowly to reduce surging and PIO tendencies when attempting to maintain constant tension (paragraph 43).

88. In tow cruise, the skew angle should be monitored closely to prevent wind drift from causing skew angles to reach aircraft limits (paragraph 43).

89. Both the pilot and copilot should be provided with an instrument that combines skew angle and tow tension in one unit (paragraph 44).

90. HH-3F towing operations should not be conducted without a fully functional AFCS and altitude coupler (paragraph 45).

91. The last 40 feet of the tow cable from the free end should be color coded (paragraph 46).

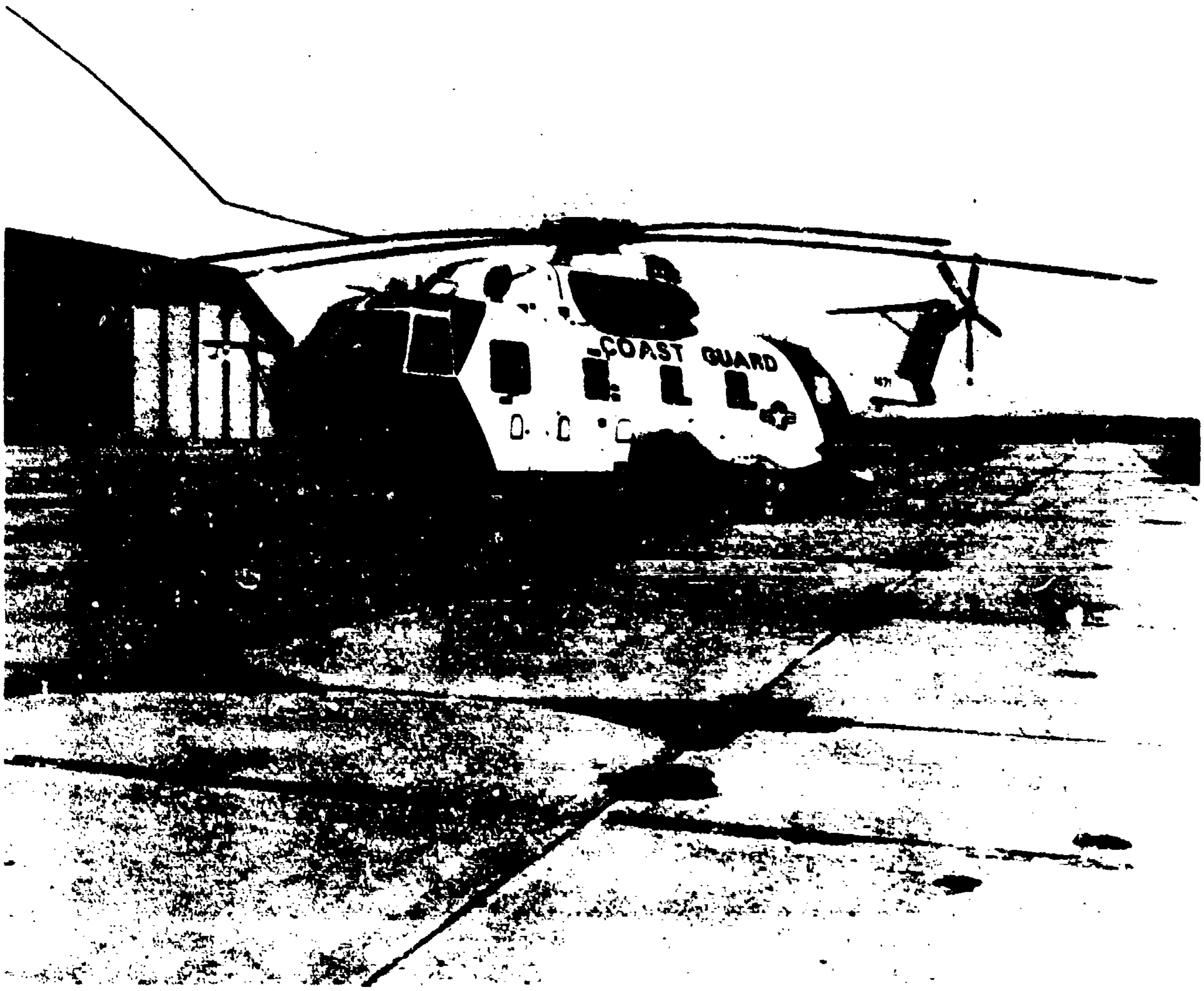

Figure A-1
HH-3F Helicopter
CG-1471
3/4 Forward View

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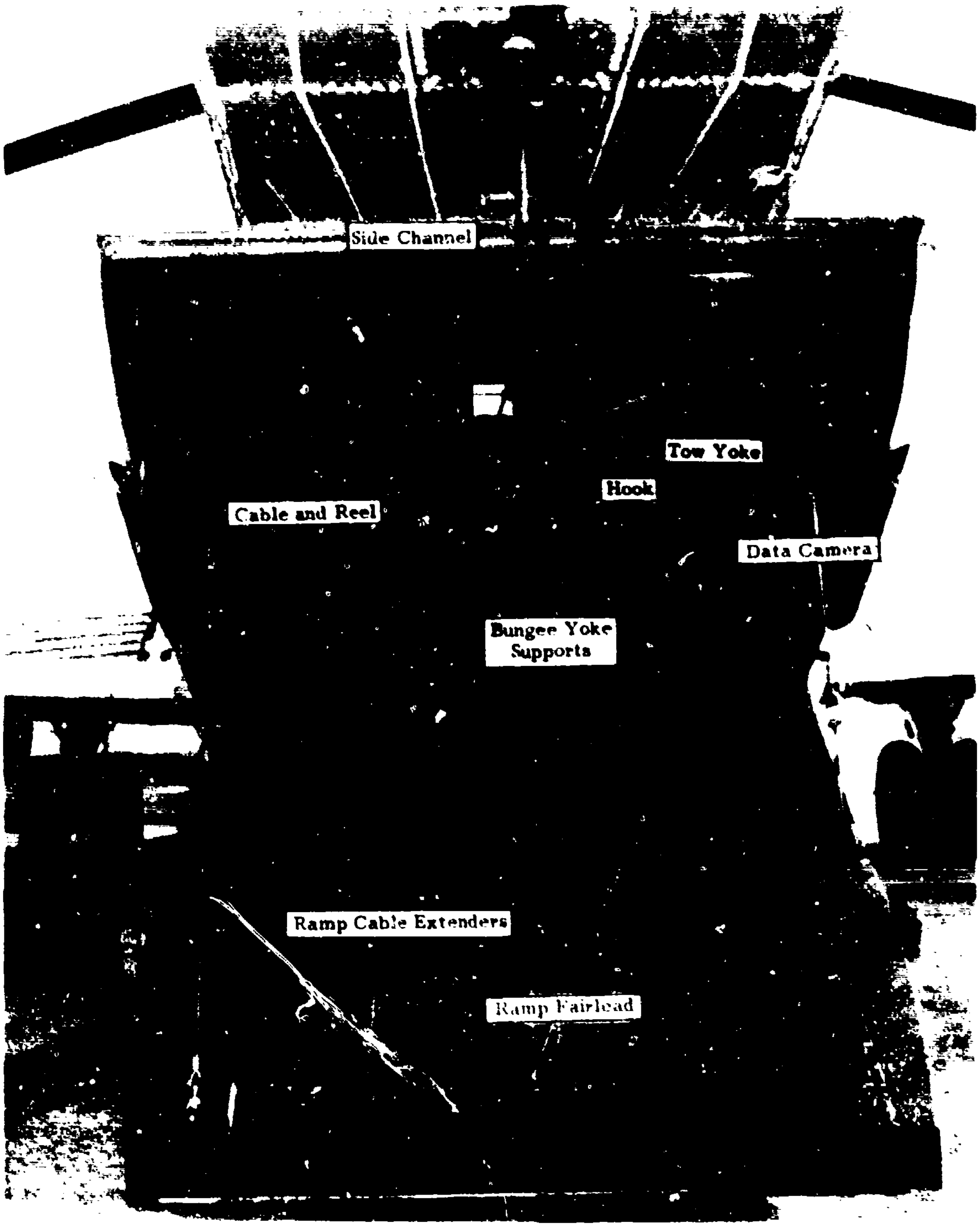


Figure A-2
HH-3F Helicopter
CG-1471
Tow Equipment - Looking Forward

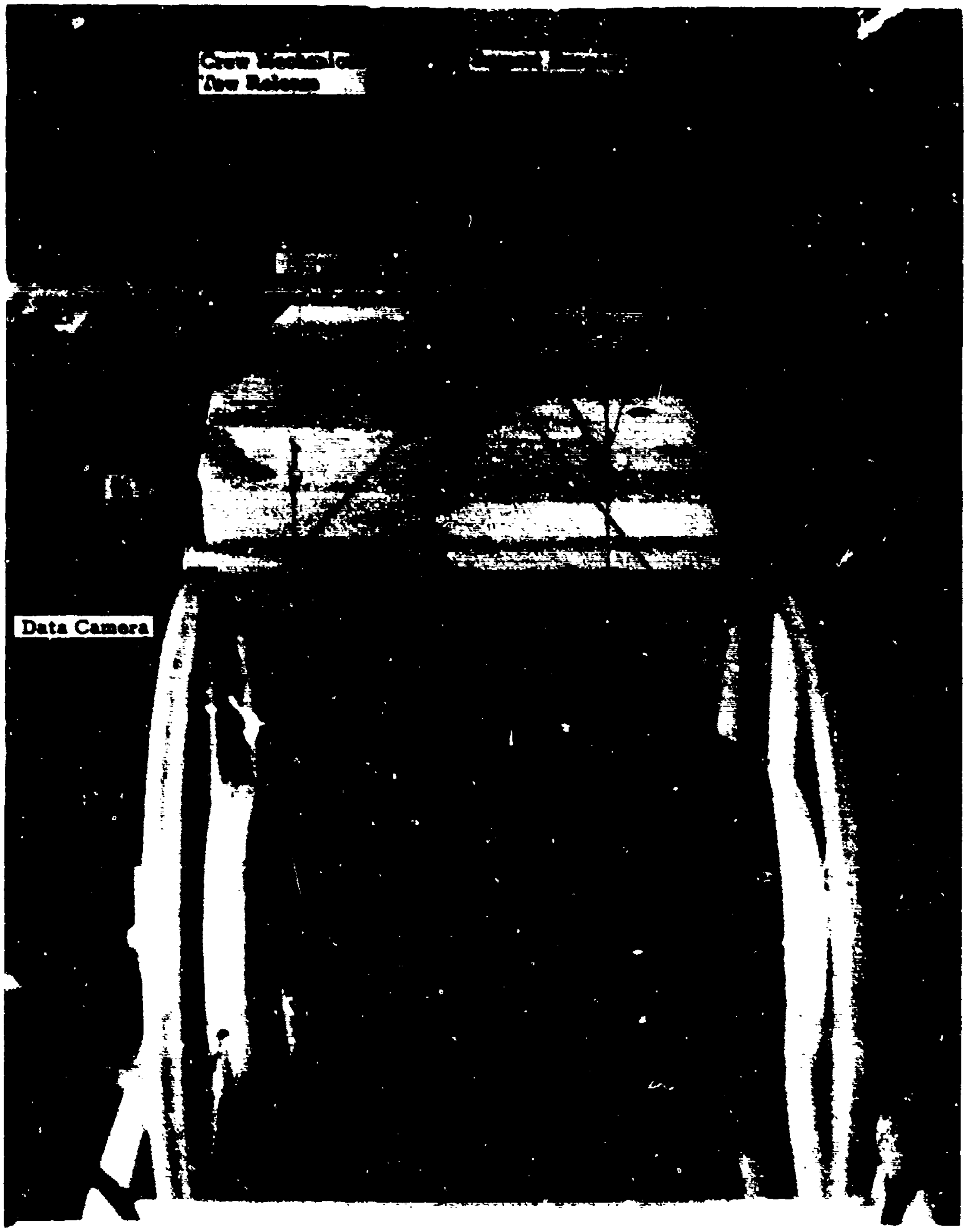


Figure A-3
HH-3F Helicopter
CG-1471
Tow Equipment - Looking Aft

Figure A-4
HH-3F Helicopter
CG-1471
Empty Sled (FSD)

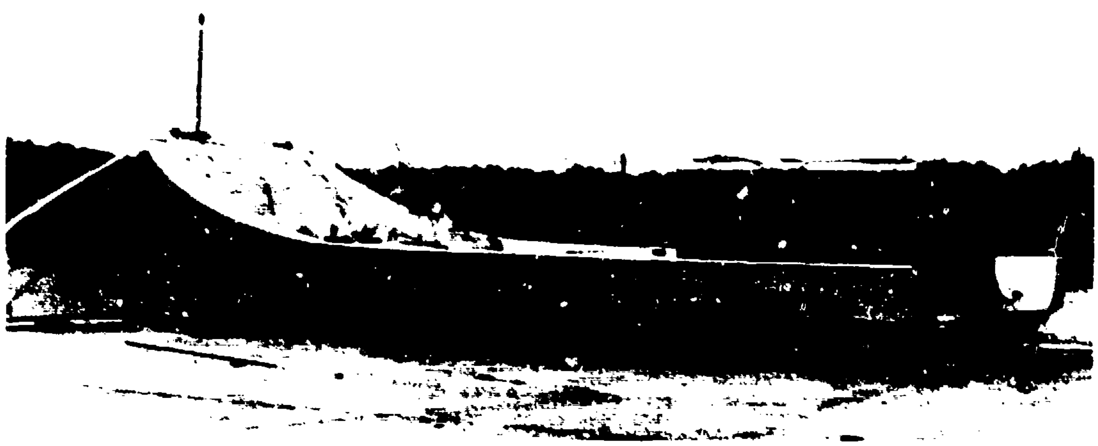


Figure A-5
HH-3F Helicopter
CG-1471
Sled and ADAPTS

Figure A-6
HH-3F Helicopter
CG-1471
Sled and Barrier

Figure A-7
HH-3F Helicopter
CG-1471
S'ed and Recovery Device

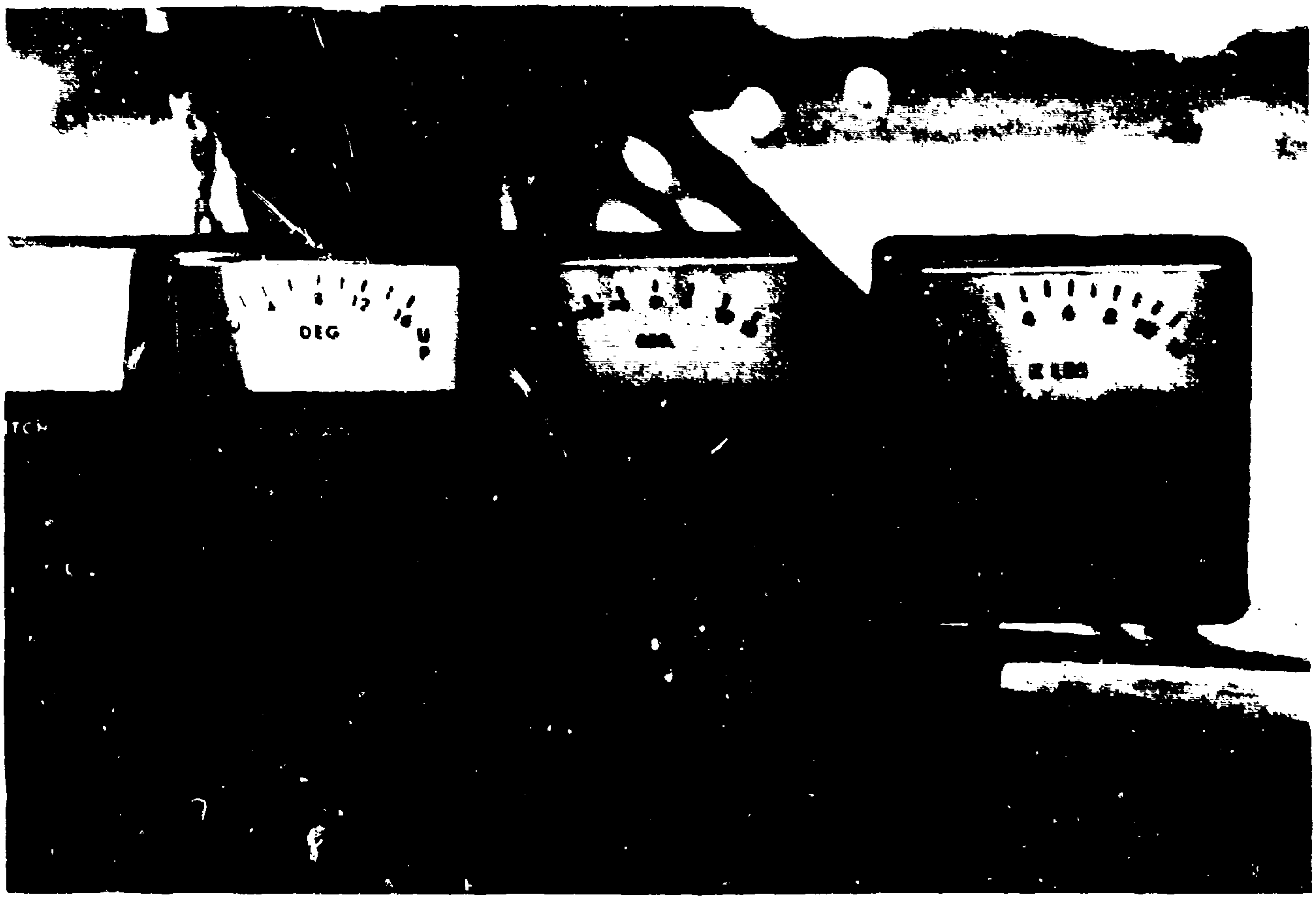


Figure A-8
HH-3F Helicopter
CG-1471
Cockpit Tow Indicators

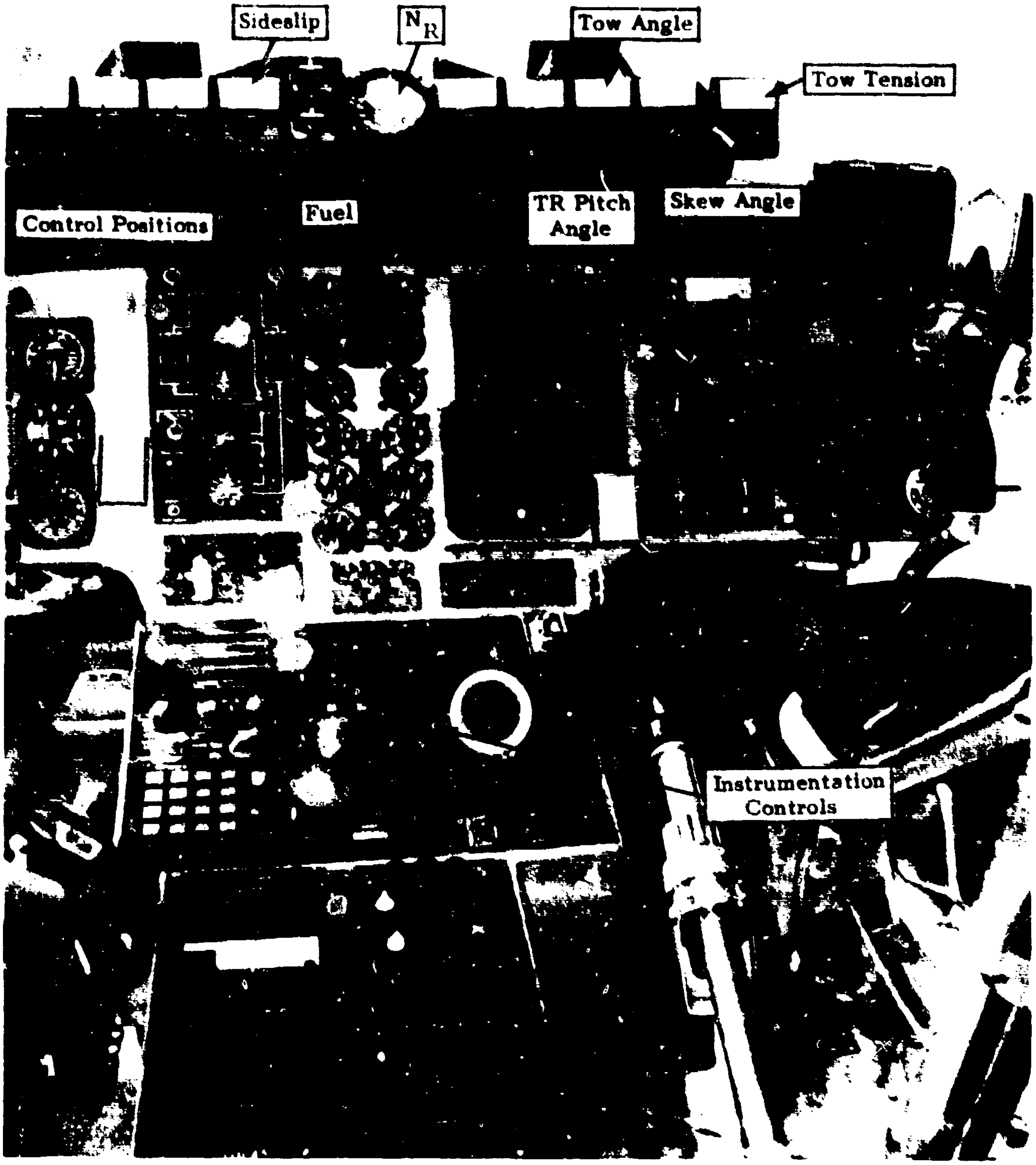


Figure A-9
HH-3F Helicopter
CG-1471
Instrumentation and Electrical Cable Release (O)

DESCRIPTION OF HARDWARE

1. The tow hardware for the HH-3F is designed to be two-man portable and fully functional without powered assist. It is also designed to be easily and quickly installed and removed from the helicopter with a minimum of permanently installed equipment. The permanently installed hardware includes airframe hard points, load sensor electronic box, cockpit indicator, electrical wiring, and a lifeline. Portable or removable equipment includes ramp fairlead, tow cable on reel litter, yoke assembly, quick release hook, and rewind motor with battery pack.

2. The tow cable is 600 feet of 5/8-inch diameter Kevlar core line with eyes spliced in each end. The approximate weight of the tow cable is 100 pounds. Attachment of the cable to the aircraft is by a twin jaw hook mechanism. The hook mechanism is designed to reliably hold the cable under all load conditions, yet be capable of quickly releasing the cable with minimum release forces or release of stored strain energy. This is done with an over-center toggle mechanism to control the positioning of the twin jaws. Over-center stops in one direction provide for self-locking of the jaws under load while free over-center motion in the opposite direction allows the jaws to open freely under load. The hook is closed on the cable eye by a manually operated lever located on the right side of the hook. Release of the hook can be accomplished in four ways: (1) mechanical release on the hook, (2) emergency remote mechanical release forward of the yoke, (3) emergency electrical release from the cockpit, and (4) automatic electrical overload release at 12,000-pounds tension.

3. The quick release hook is attached to a delta-shaped yoke by a load measuring bolt. Strain gage signals from the bolt are processed in a remotely located processor box and displayed to the pilots on a calibrated d-Arsonval meter in the cockpit, Appendix A, figure 8. The hook skew angle is measured by a rotary potentiometer and the angle displayed on a second cockpit meter. A similar system is used to measure the yoke elevation angle and display the information in the cockpit.

4. Lateral hook motion or skew angle is limited by external stops and lateral cable skew is limited by cables used to support the aft ramp. Cable extensions are required to allow additional down travel of the aft ramp to maximize the nose-down attitude available for towing. A smooth wood fairlead, Appendix A, figure 2, is screwed to the aft end of the aft ramp to prevent sharp bends or rough surfaces from damaging the tow cable should contact occur at high tow angles.

5. Tow forces from the hook are transmitted up the two legs of the yoke. Inward loads on the yoke legs are mutually relieved by a compression strut between the legs near the attach points to the airframe. The prototype installation used 5/8-inch bolts at all joints. A production installation would utilize lockpins for easier installation and removal.

6. The airframe is reinforced with a 7-inch wide formed channel between frames 323 and 346.5. Loads from the yoke arms are introduced to the channel by a lug bar bolted to the channel. The channel and lug are permanent additions to the airframe.

7. The starboard yoke arm holds the emergency manual release handle and release cable. The handle is located near the operator's position for the aft ramp controls.

8. The tow cable is stored on a garden hose type reel which is tied down to floor fittings forward of the yoke compression strut. Quick release latches are used on all four legs and are similar to those used on troop seats. The cable is deployed by lowering the end over the ramp edge and controlling run-out rate by hand or foot pressure on the reel rim. Cable retrieval may be manual by hand-over-hand operation of the reel rim or powered by a portable battery operated power handle. The power handle is plugged into a 1/2-inch drive receptacle on a reduction gear assembly on the port side of the reel. The power handle used for this evaluation was underpowered.

9. A lifeline is permanently installed on the port side of the aircraft between stations 362 and 481. The 7/32-inch diameter steel cable provides an anchor point for a crewman's safety harness while working aft of the yoke assembly, such as during cable hookup and release. The lifeline is approximately 18 inches above the deck and is anchored to the airframe by 1/4-inch thick plates bolted to the flanges of available frames by four or more number 10 bolts.

LOAD STRESS ANALYSIS

10. The tow hardware designed for the HH-3F helicopter is sized for a working load of 6,000 pounds. The limit load is 12,000 pounds cable tension, and the maximum lateral skew angles are ±15 degrees. The cable tension forces are transferred to the helicopter structure by means of a triangular yoke with a schematic plan view shown in figure 1.

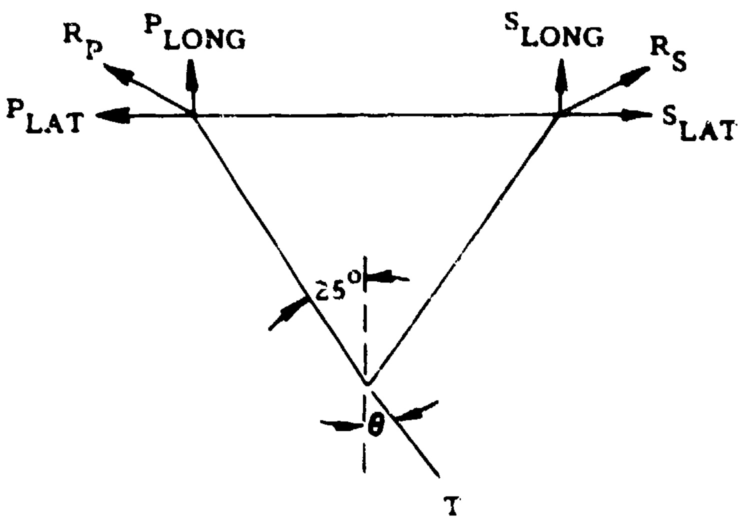


Figure B-1

The relationship of the yoke leg tension as a function of cable tension (T) and skew angle (θ) are shown in table I.

Table B-I

Skew Angle	0 degree	5 degrees	10 degrees	15 degrees
R_s	.55T	.653T	.749T	.838T
R_p	.55T	.446T	.338T	.227T

Lateral load as a function of cable tension and skew angle is shown in table II.

Table B-II

Skew Angle	0 degree	5 degrees	10 degrees	15 degrees
P_{lat}	.23T	.27T	.31T	.35T
S_{lat}	.23T	.188T	.143T	.096T

A safety factor of 1.5 is applied to the anticipated limit load of 12,000-pounds tension for a design ultimate load of 18,000 pounds. Thus, the maximum yoke tensile load will be:

$$R_{p_{max}} = (0.838)\ (18,000) = 15,084 \text{ pounds}$$

The yoke arms are 6061-T6 aluminum alloy with welded end fittings with a minimum ultimate strength of 22,000 psi. Therefore, the minimum yoke arm area is:

$$A_{min} = \frac{15,084}{22,000} = 0.686 \text{ inch}^2$$

This area was satisfied with 3-inch outside diameter (O.D.) tubing with a wall thickness of 0.083 inch or greater. A compression strut between the attachment points of the yoke arms to the airframe was provided. The maximum compressive load was computed to be:

$$P_{lat} = (0.35)\ (18,000) = 6,300 \text{ pounds}$$

The minimum section modulus for the compression strut is computed from Euler's equation for a column with pinned ends:

$$I_{min} = \frac{(6300)\ (74)^2}{2\ (10^7)} = 0.349 \text{ inch}^4$$

This section modulus can be met by a 2.25-inch O.D. tube with a minimum thickness of 0.095 inch.

11. The required line of action of the tow forces dictated a transfer of loads into the helicopter airframe in the vicinity of station 350. The hard point added to the airframe distributed the loads between the frames at stations 323 and 346.5 at approximately water line (W.L.) 149.

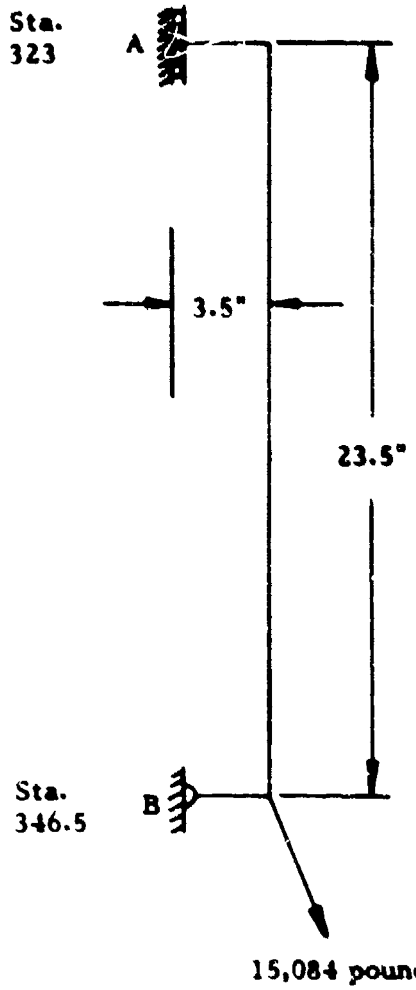
12. Sikorsky Engineering Report SER 61732 was utilized to determine the size, strength, and loading of frames 323 and 346.5. The Sikorsky structural analysis showed the major frame, 346.5, to be critical during ground and hydrodynamic loading and not critical for even the most severe flight conditions. Consequently, there was more than adequate margin to superimpose the tow forces to the airframe in this region.

13. The effects of the tow forces on the two frames are analyzed with several simplifications in figure 2.

$$M_B = 0$$

$$0 = A(23.5 - 15{,}084 \cos 25^{\circ})(3.5)$$

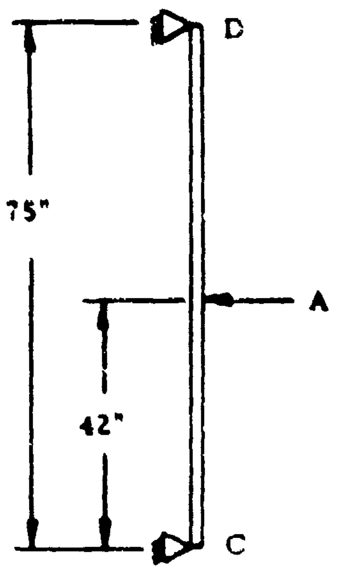
$$A = 2{,}035 \text{ pounds}$$



The section modulus of frame 323 including local skin is computed to be 0.9983 inch^4

Figure B-2
Plan View of Port Hard-point Schematic

14. The vertical section of frame 323 is simplified to a simply supported center-loaded beam in figure 3.



$$D = 2{,}035\,\frac{(75-42)}{75} = 895 \text{ pounds}$$

$$C = 2{,}035-895 = 1{,}139 \text{ pounds}$$

The maximum bending moment is computed to be:

37,587 inch-pounds

The maximum stress in frame 323 is:

$$\sigma = \frac{(37{,}587)\,(1.75)}{.9983} = 65{,}889 \text{ psi}$$

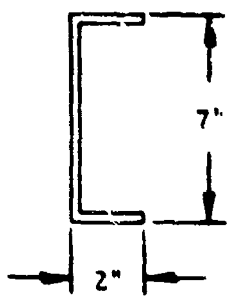
Figure B-3

15. The frame is predominantly 7075-T6 aluminum alloy with an ultimate stress of 73,000 psi with a minimum margin of safety of:

$$\frac{73{,}000}{65{,}889} - 1 = +0.108$$

This is actually conservative, as the frame is in reality a curved beam with essentially fixed ends which serves to relieve the stress levels shown from a simplified analysis.

16. Next, the strength of the hard point between frames 323 and 346.5 is considered. A channel section shown in figure 4 will span the frames.



The axial load carried through the channel will produce the following stress:

$$\sigma = \frac{15{,}084\,(\cos 25^{\circ})}{(7+2+2)\,(.125)} = 9{,}942 \text{ psi}$$

Figure B-4

This is quite low and satisfactory.

17. The load from the hard-point channel is introduced to the airframe as bearing loads in the frame cap members. The caps are one 0.090-inch strap and one 0.094-inch angle, both of 7075-T6 aluminum alloy. Approximately 16 number 10 screws are used on each frame member.

$$\sigma_{br} = \frac{(15{,}084)\cos 25\ \text{degrees}}{2\,(16)\,(.190)\,(.184)} = 12{,}219\ \text{psi}$$

This compares with an ultimate bearing strength of 108,000 psi for 7075-T6.

18. Additionally, there is a stepped bar which introduces the yoke loads to the channel member. The bar is attached to the channel with 12 number 10 screws and 2.25-inch bolts. The total bolt shear strength is adequate, as there is a total of 32,860 pounds shear strength available as shown below:

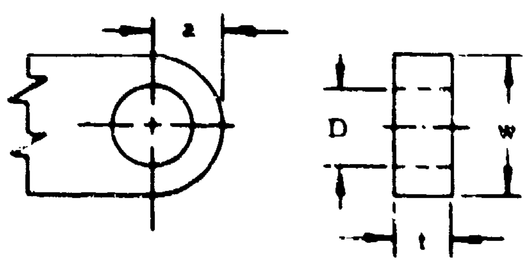
$$(12)\,(2125) + 2(3680) = 32{,}860\ \text{pounds}$$

The bearing strength of the channel is checked below:

$$\sigma_{br} = \frac{(15{,}084)\,(\cos 25\ \text{degrees})}{(2(.25) + 12\,(.190))\,.125} = 39{,}340\ \text{psi}$$

This compares with an ultimate bearing strength of 97,000 psi for 2024-T4 plate.

19. Numerous connections between hook, yoke, and hard points are made with pinned lugs as shown in figure 5. An analysis of the critical lug is presented below and other deviations from this are more conservative.



D = 0.625"

a = 1.25"

w = 1.75"

t = 0.875"

Figure B-5

20. Design curves and empirical data are referenced to the Sikorsky Structures Manual, Section 5.3.

$$P_{ay} = K_t A_t F_{ty} = (0.52)\,(0.984)\,(36{,}000)$$

$$= 18{,}420\ \text{pounds}$$

P_{ay} is the allowable load without yield using 5052-T6 aluminum alloy and is well above the 15,084 pounds per leg maximum axial load.

21. Next, transverse loads are considered and

$$P_{try} = K_{try} A_{br} F_{ty} = (1.11)\ (.546)\ (36{,}000)$$

$$= 21{,}818 \text{ pounds}$$

P_{try} is the allowable load without yield in other than an axial direction and is well above the maximum of 6,300 pounds per leg in the lateral direction. The pin to be used in each leg is a 5/8-inch bolt with a shear capacity of 23,000 pounds in single shear or 46,000 pounds per pinned joint.

22. The tow yoke was attached to the quick release hook by a 1.125-inch diameter load sensing bolt which was designed by Strainsert for working loads up to 15,000 pounds. Proof test results for the quick release hook are included in lieu of detailed stress analysis. The hook was proof loaded to 18,000 pounds with no permanent deformation. Approximately 100 releases - mechanical, electrical, and automatic electrical - were made at load levels between 3,000 and 12,000 pounds. No failures occurred during any portion of the test program.

23. The tow cable selected was parallel fiber Kevlar core with a neoprene inner protective cover and braided-nylon outer abrasion cover. The Wall Rope Company trade name for this configuration is Uniline. The nominal 5/8-inch diameter cable was quoted to have a 38,000-pound breaking strength with 100-percent strength eye splices on each end. Conventional reduction factors call out approximately a 6 to 1 ratio of ultimate to working strength; this was adhered to in selecting the cable size based on the 6,000-pound working load. The tow cable is stored on a rotating reel. The structure of the reel is designed primarily by crash loads. The weight of the cable with terminals is approximately 100 pounds. The cable reel is secured to four floor-tiedown fittings, each of which has a capacity of 2,500 pounds. On this basis, 20 g loadings in all directions could be restrained by any one tiedown fitting.

Table C-I

Sled Configuration

Configuration	Gross Weight (pounds)	Center of Gravity (feet from stern)
Sled (empty)	10,200	25.1
Sled and ADAPTS	15,900	18.2
Sled and Barrier	25,500	15.3
Sled and Lockheed Device	23,800	18.2

Table C-II

Scope of Ground Tests

Electrical Inspection	Ensure safe and proper wiring.
Electromagnetic Interference	Define areas of tensiometer error and hook release caused by other aircraft systems.
Cockpit/Crew Station Arrangement	(a) Evaluate cockpit tensiometer/skew angle indicator placement and readability for pilot/copilot scan. (b) Define crew positions and determine safety and comfort.
Tow Equipment	Determine the effort required to install/remove tow hardware and define any safety/special tool requirements.

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Table C-III

Scope of Flight Tests

Test (1)	Gross Weight (pounds)	Wind Direction (degrees)	Tension (pounds)
Static Tow Performance	17,000 18,000 19,000	000 090 180 270	0-6,000 1,000-pound increments
Static Tow Static Stability	17,000 18,000 19,000	000 090 180 270	0-6,000 1,000-pound increments
One-Engine Inoperative	18,000	000 090 180 270	0-3,000 5,000
AFCS Hardovers	18,000	000 090 180 270	3,000-5,000
Dynamic Tow (2) Performance (each device)	18,500	Various	0-6,000
Dynamic Tow Static Stability	18,500	Various	0-6,000
Gust Response	18,500	Various	0-6,000
Tow Procedures	18,500	Various	0-6,000

Tow Altitude: 75-feet to 100-feet AGL

NOTES: (1) Tests conducted under day, VMC only
(2) All dynamic tow tests conducted up to seas of significant wave height of 3 to 5 feet.

Table C-IV

Flight Limitations

Torque Limits:	
Normal Power:	
Dual Engine	86 percent
Single Engine	103 percent
Military Power:	
Dual Engine	103 percent
Single Engine	123 percent

Power Turbine Inlet

Temperature Limits (T_5):	
Normal Power	660°C
Military Power	696°C

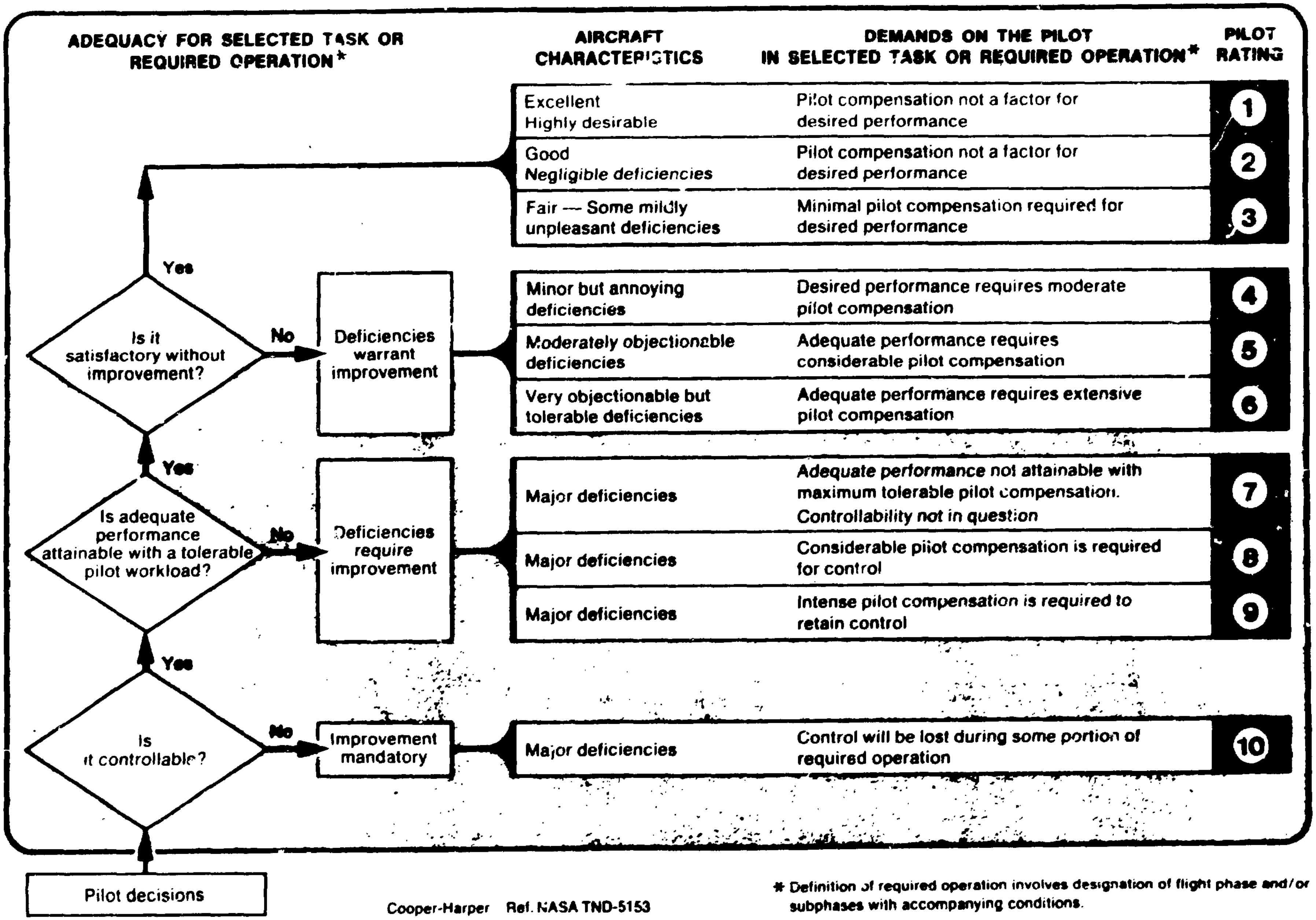
Maximum Gross Weight 22,020 pounds

Airspeed Limits:	
Forward Flight	142 knots
Sideward Flight	35 knots
Rearward Flight	30 knots

Center of Gravity Limits: See figure 1, Appendix E

Table C-V

Handling Qualities Rating Scale



Cooper-Harper Ref. NASA TND-5153

* Definition of required operation involves designation of flight phase and/or subphases with accompanying conditions.

Table C-VI

HH-3F Tow Envelope Development
Instrumentation Parameters

AIRBORNE MAGNETIC TAPE

Longitudinal Cyclic Position	Main Rotor Torque
Lateral Cyclic Position	Tail Rotor Torque
Directional Pedal Position	No. 1 and No. 2 Engine T_5
Collective Position	CG Load Factor
Sideslip	Tow Boom Elevation
Skew Angle	Pitch Angular Acceleration
Tail Rotor Pitch	Roll Angular Acceleration
Outside Air Temperature	Yaw Angular Acceleration
Airspeed	Intermediate G. B. Oil Temperature
Main Rotor Speed	Tail Gearbox Oil Temperature
No. 1 and No. 2 Engine Torque	CG Vertical Acceleration
Tow Tension	CG Lateral Acceleration
Fuel Used	CG Longitudinal Acceleration
No. 1 and No. 2 Fuel Temp	Pilot Seat Vertical Acceleration
Barometric Altitude	Pilot Seat Lateral Acceleration
Radar Altitude	Copilot Seat Vertical Acceleration
Pitch Attitude	Copilot Seat Lateral Acceleration
Roll Attitude	No. 1 and No. 2 Engine Fwd Mount Longitudinal Acceleration
Yaw Attitude	No. 1 and No. 2 Engine Fwd Mount Vertical Acceleration
Pitch Rate	No. 1 and No. 2 Engine Fwd Mount Lateral Acceleration
Roll Rate	Time Code
Yaw Rate	

COCKPIT DISPLAY

Longitudinal Cyclic Position	No. 1 and No. 2 Engine Torque
Lateral Cyclic Position	Tow Tension
Directional Pedal Position	Fuel Used
Collective Position	Time Code
Sideslip	No. 1 and No. 2 Turbine Inlet Temperature
Skew Angle	Barometric Altitude
Tail Rotor Pitch	Radar Altitude
Outside Air Temperature	Transmission Oil Temperature
Airspeed	Tow Cable Angle
Main Rotor Speed	

Table C-VII

RF Bonding Matrix

Item Measured	Resistance in Milliohms
NO TENSION	
Skew Angle Indicator	2600
Tow Angle Indicator	18
Tow Tensiometer	14
Electrical Solenoid	1
Tension Controller	3.4
1000-POUNDS TENSION	
Skew Angle Indicator	2600
Tow Angle Indicator	18
Tow Tensiometer	14
Electrical Release Solenoid	1
Tension Controller	3.4

Table C-VIII

HH-3F/FSD Tow System Characteristics

HH-3F Tow Characteristics

Towed Vehicle	Planing Indicated Airspeed (KIAS)	Planing Tension (lb)	Optimum Indicated Airspeed (KIAS)	Optimum Tension (lb)
Sled	30	1,000	34	1,900
Sled and ADAPTS	34	2,500	40	3,600
Sled and Barrier	41	3,500	46	4,500
Sled and Recovery Device	37	3,500	44	4,500

Towed Vehicle Characteristics

Towed Vehicle	Planing Water Speed (kt)	Planing Tension (lb)	Optimum Sled Water Speed (kt)	Optimum Tow Tension (lb)
Sled	17.0	1,000	19.0	1,900
Sled and ADAPTS	24.2	2,500	28.7	3,600
Sled and Barrier	19.7	3,500	31.0	4,500
Sled and Recovery Device	[illegible]3.5	3,500	29.5	4,500

Maximum Continuous Power Tow Characteristics

Towed Vehicle	Tension (lb)	Aircraft Indicated Airspeed (KIAS)	Sled Water Speed (kt)
Sled	3,250	42.0	23.7
Sled and ADAPTS	5,000	50.0	36.0
Sled and Barrier	5,750	57.2	42.4
Sled and Recovery Device	5,750	53.2	35.7

NOTES: (1) Maximum significant wave height 3 to 5 feet
(2) Maximum Ambient Temperature 26°C
(3) Tow into the wind

AIRCRAFT AND EQUIPMENT WEIGHT AND BALANCE

EQUIPMENT

The prototype tow hardware was weighed separately at NAVAIRTESTCEN. Table I shows the results of these weighings.

Table D-I

Tow Equipment Weights

Item	Weight (lb)
Reel and Cable	176
Tow Yoke	66.3
Fairlead	5.4
Power Supply	86.3
Reel Drive Motor	21.4
Total	355.4

AIRCRAFT

The project aircraft, HH-3F helicopter, CG-1471, was weighed on the NAVAIRTESTCEN scales with instrumentation installed and with both instrumentation and the tow hardware installed. Basic weight and balance were obtained from the aircraft weight-and-balance book which remains with the aircraft custodian. The basic tow configuration assumes that one crewman is at the base of the tow yoke and the other on the ramp. The tow configuration assumes the use of the JP-4 fuel. The weight-and-balance information is summarized in table D-II.

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Table D-II

Aircraft Weight and Balance

Configuration	Weight (lb)	Center of Gravity (in. FRL)
Basic	13,803	276.[illegible]
Basic and Tow Equipment	14,158	275.6
Tow*	17,958	271.6

*3,000 pounds JP-4 fuel plus four crew

CURVES

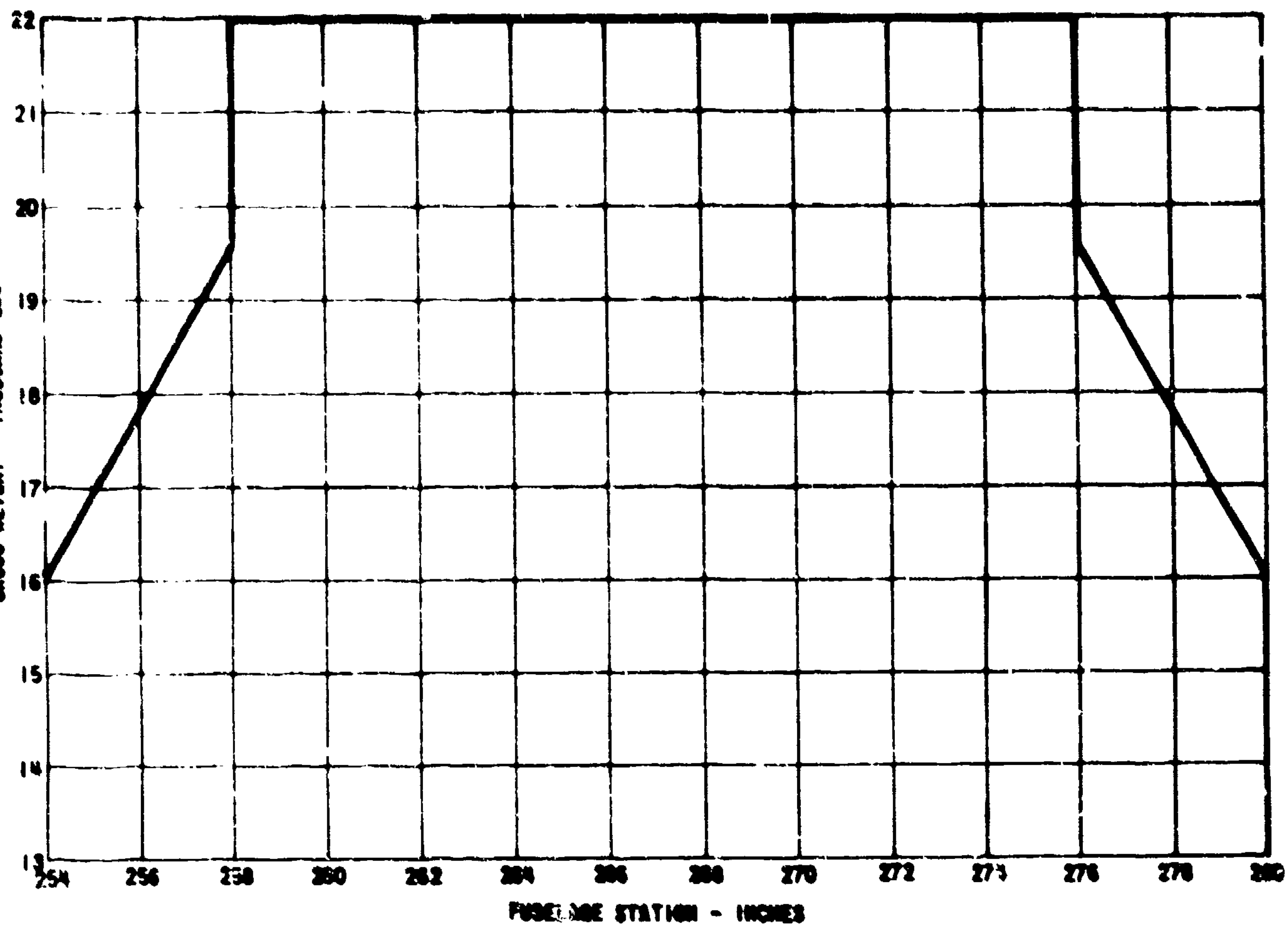

Figure E-1
HH-3F Center of Gravity Limits

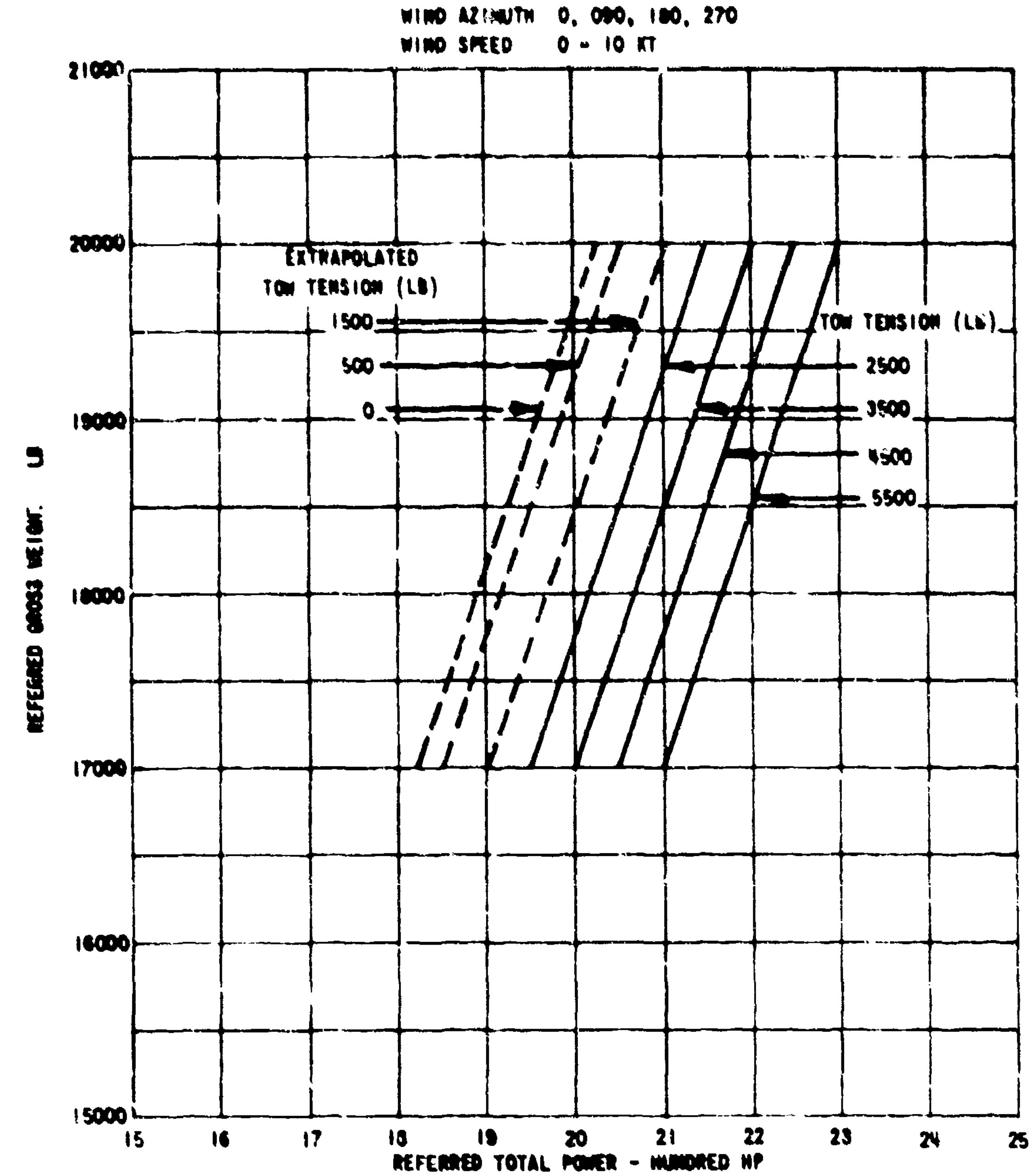

Figure E-2
HH-3F Helicopter
CG 1471
Static Tow Performance

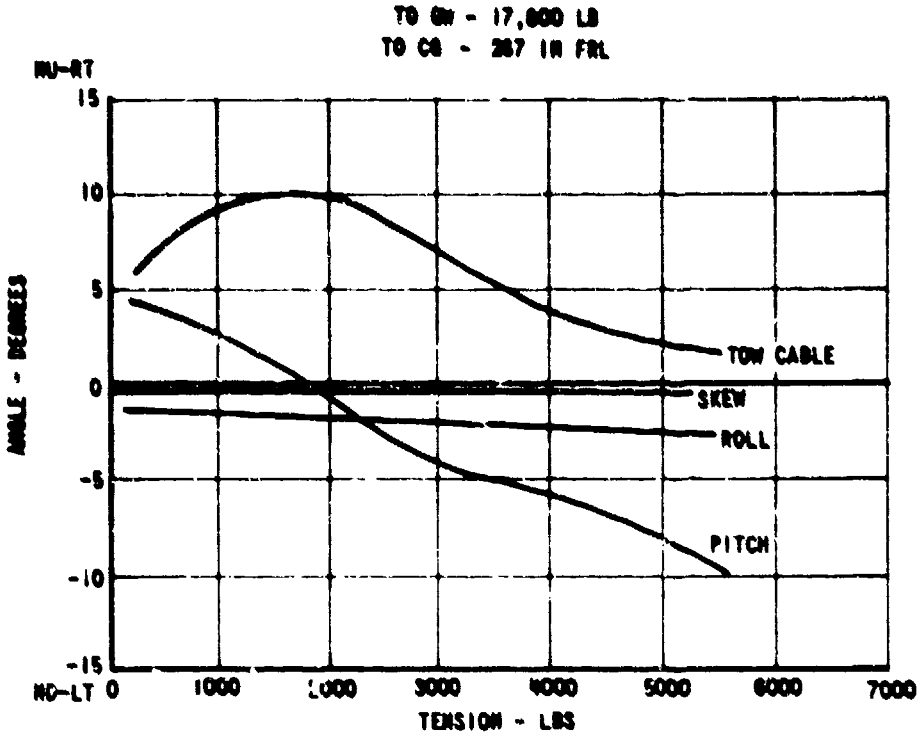

Figure E-3
HH-3F Helicopter
CG 1471
Aircraft Attitude Under Static Tow

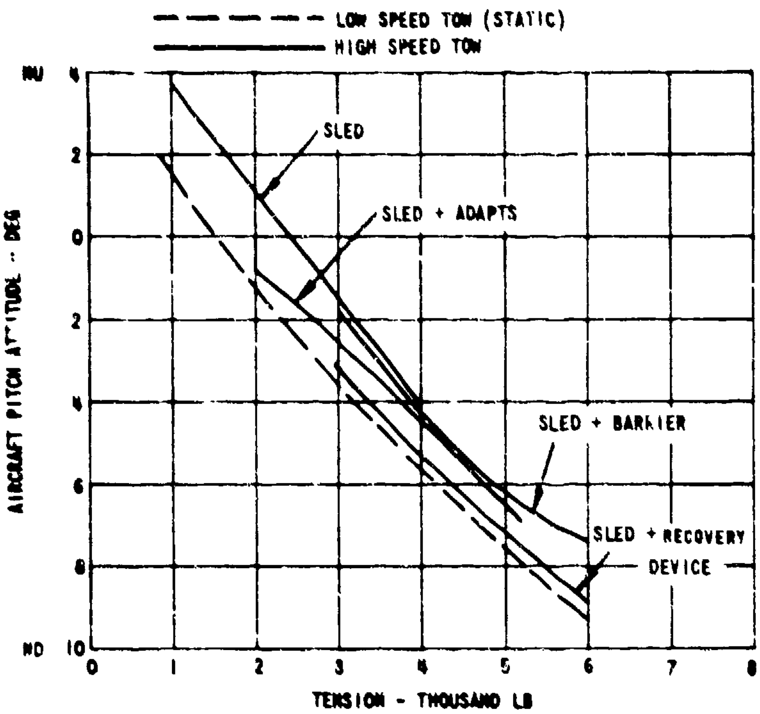

Figure E-4
HH-3F Helicopter
CG 1471
Aircraft Tow Attitude

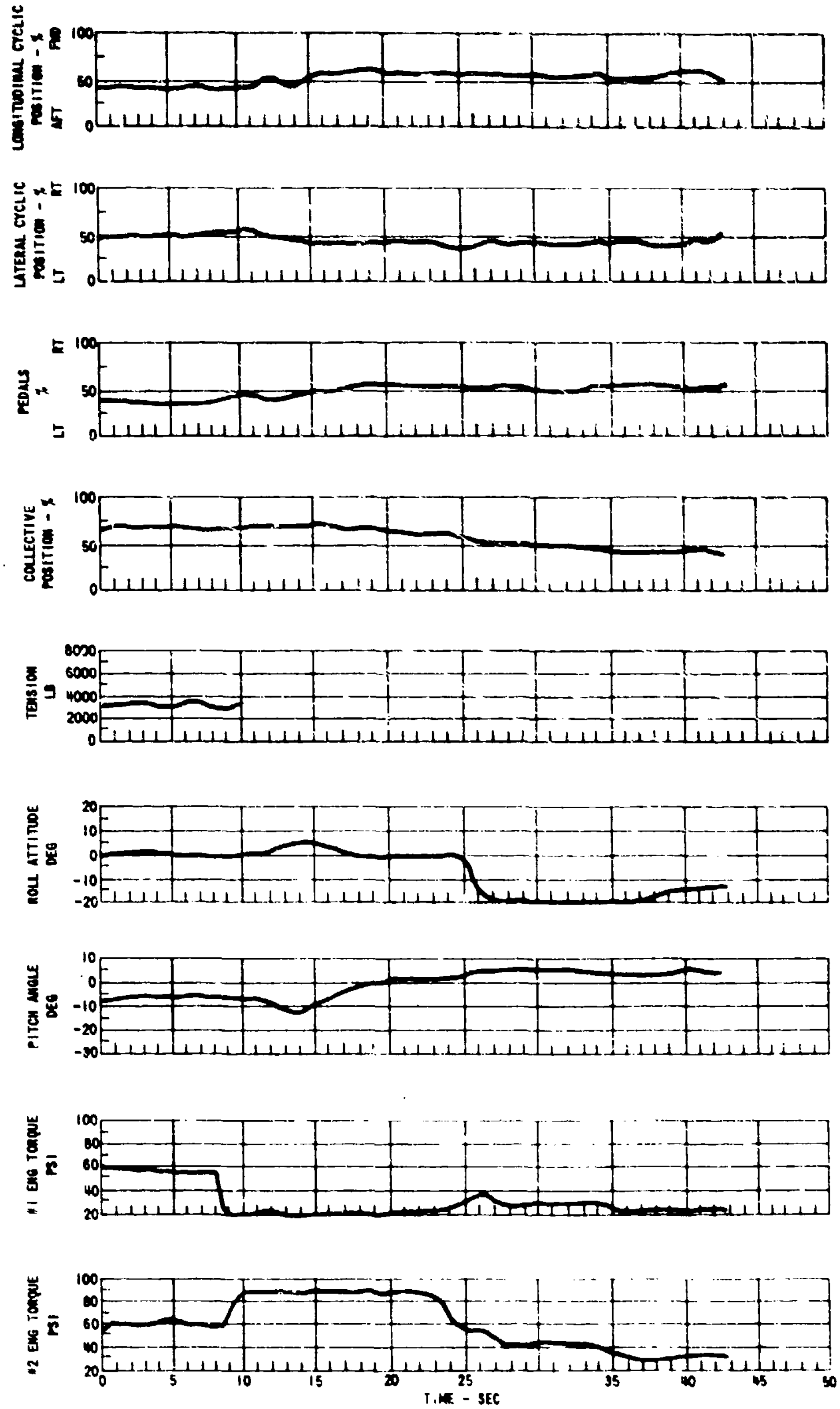

Figure E-5
Simulated Single-Engine Failure Under Tow

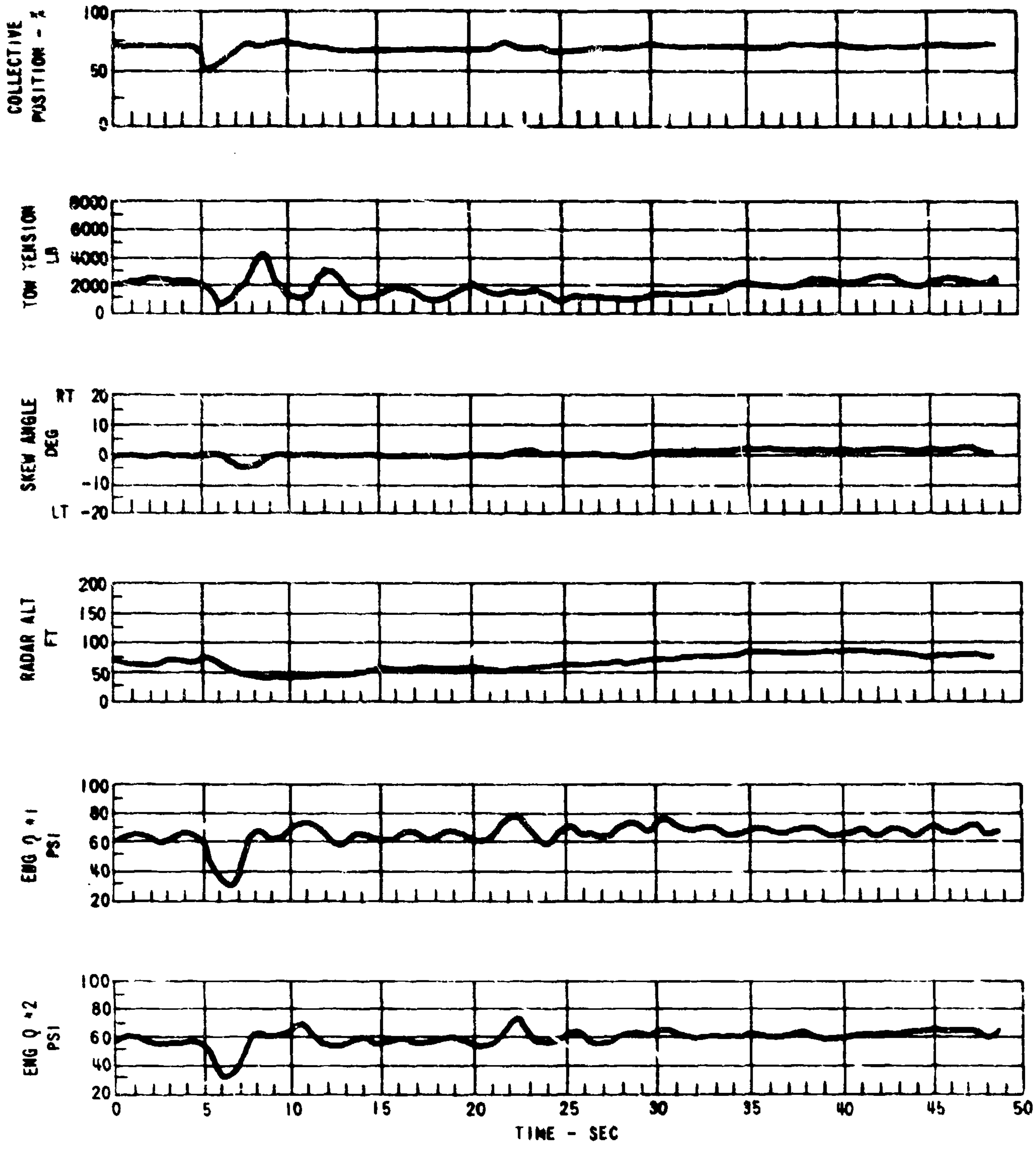

Figure E-6
HH-3F Helicopter
CG 1471
Down Collective Hardover

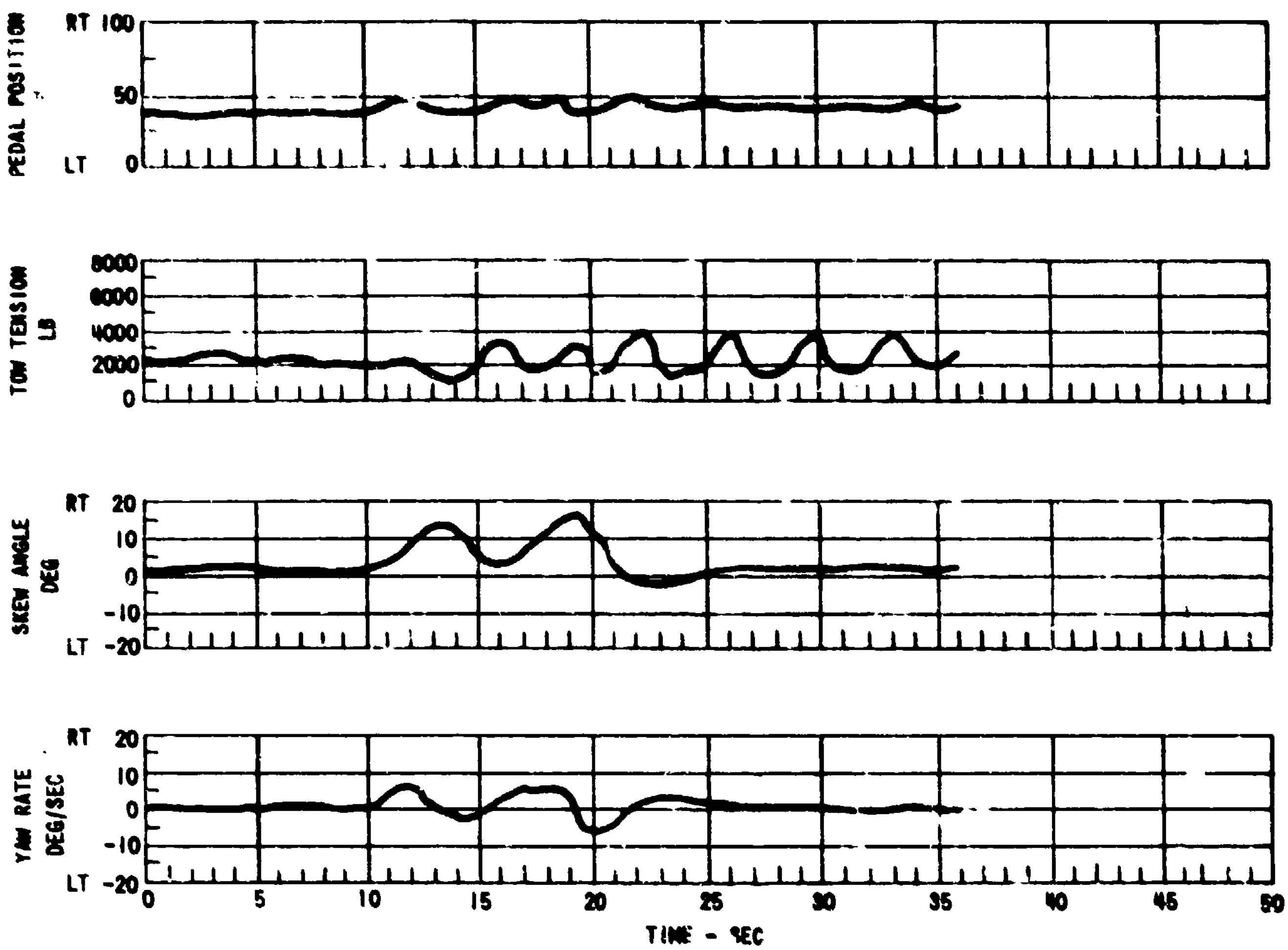

Figure E-7
HH-3F Helicopter
CG 1471
Right Yaw Hardover

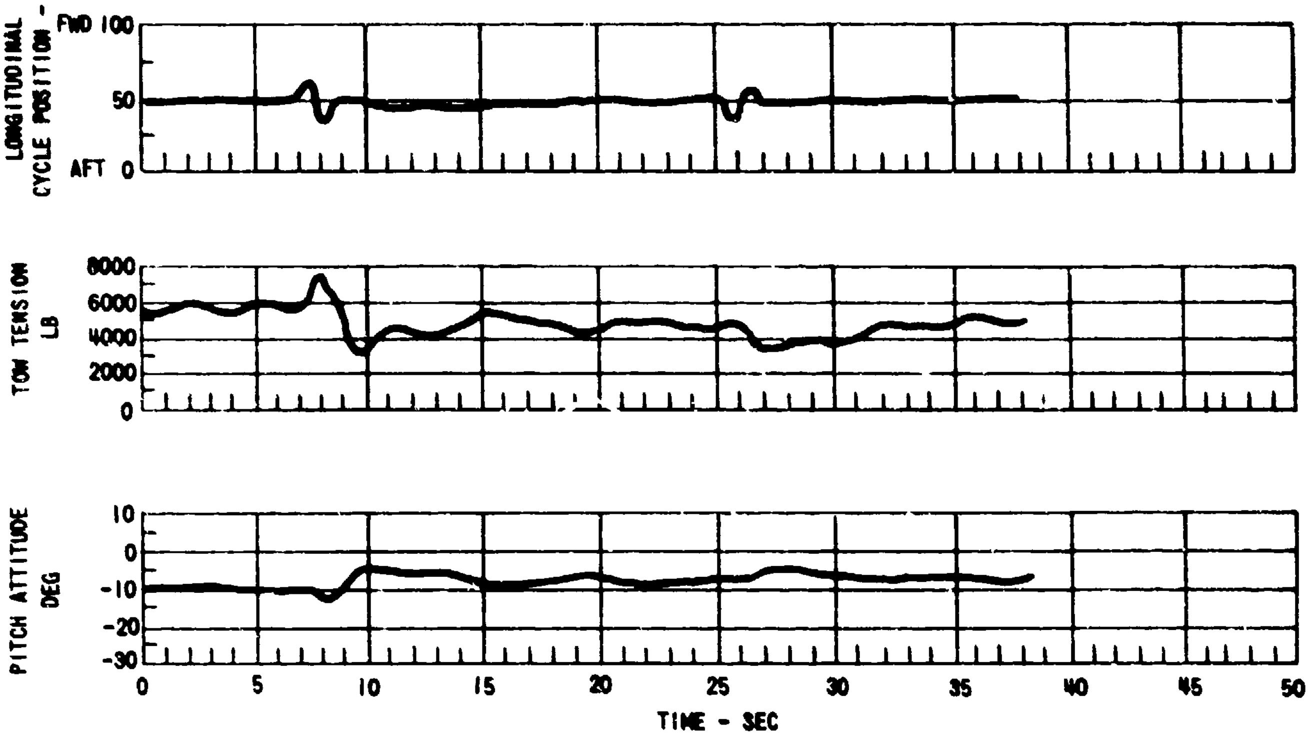

Figure E-8
HH-3F Helicopter
CG 1471
Forward Pitch Hardover

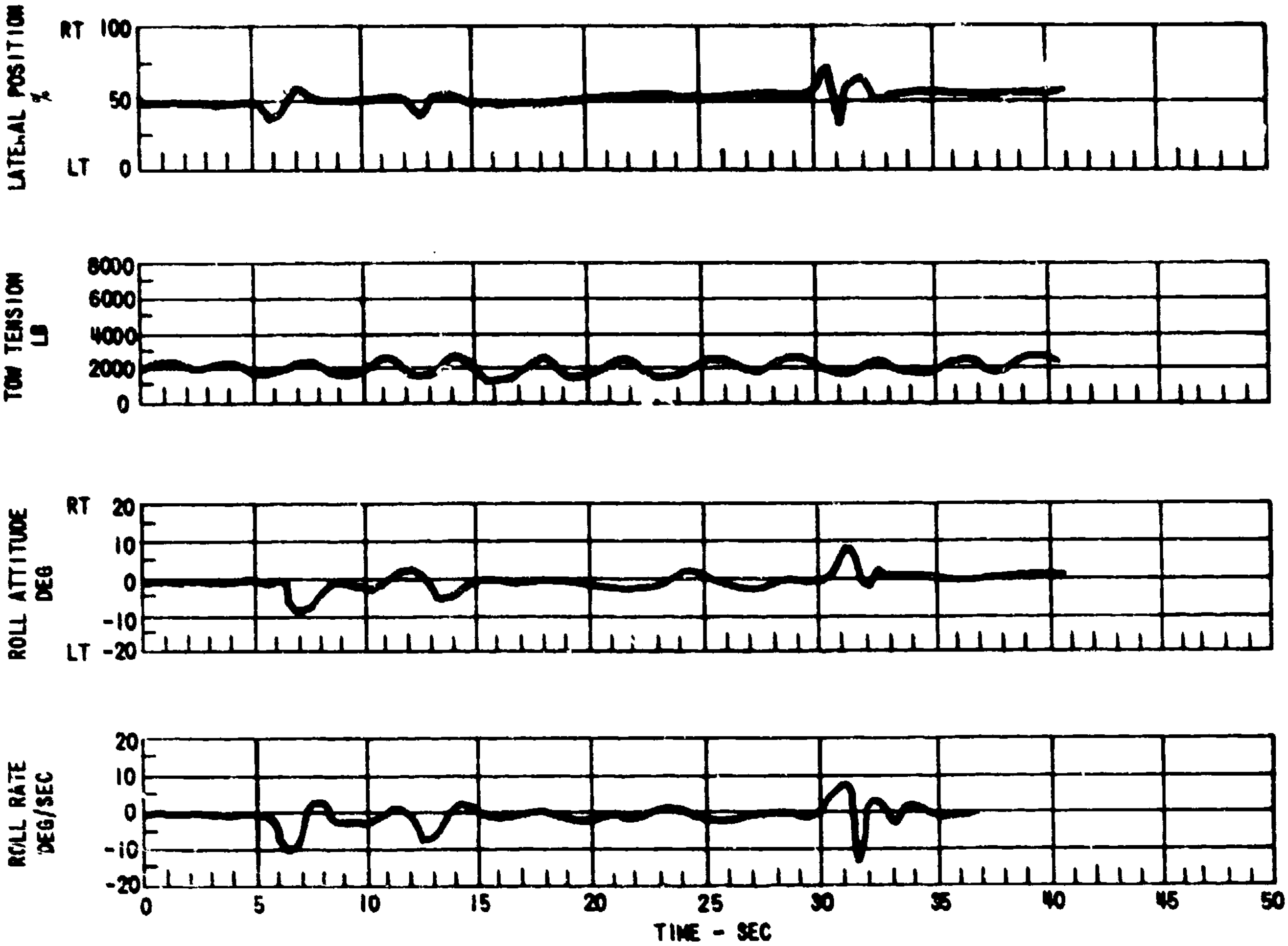

Figure E-9
HH-3F Helicopter
CG 1471
Left Roll Hardover

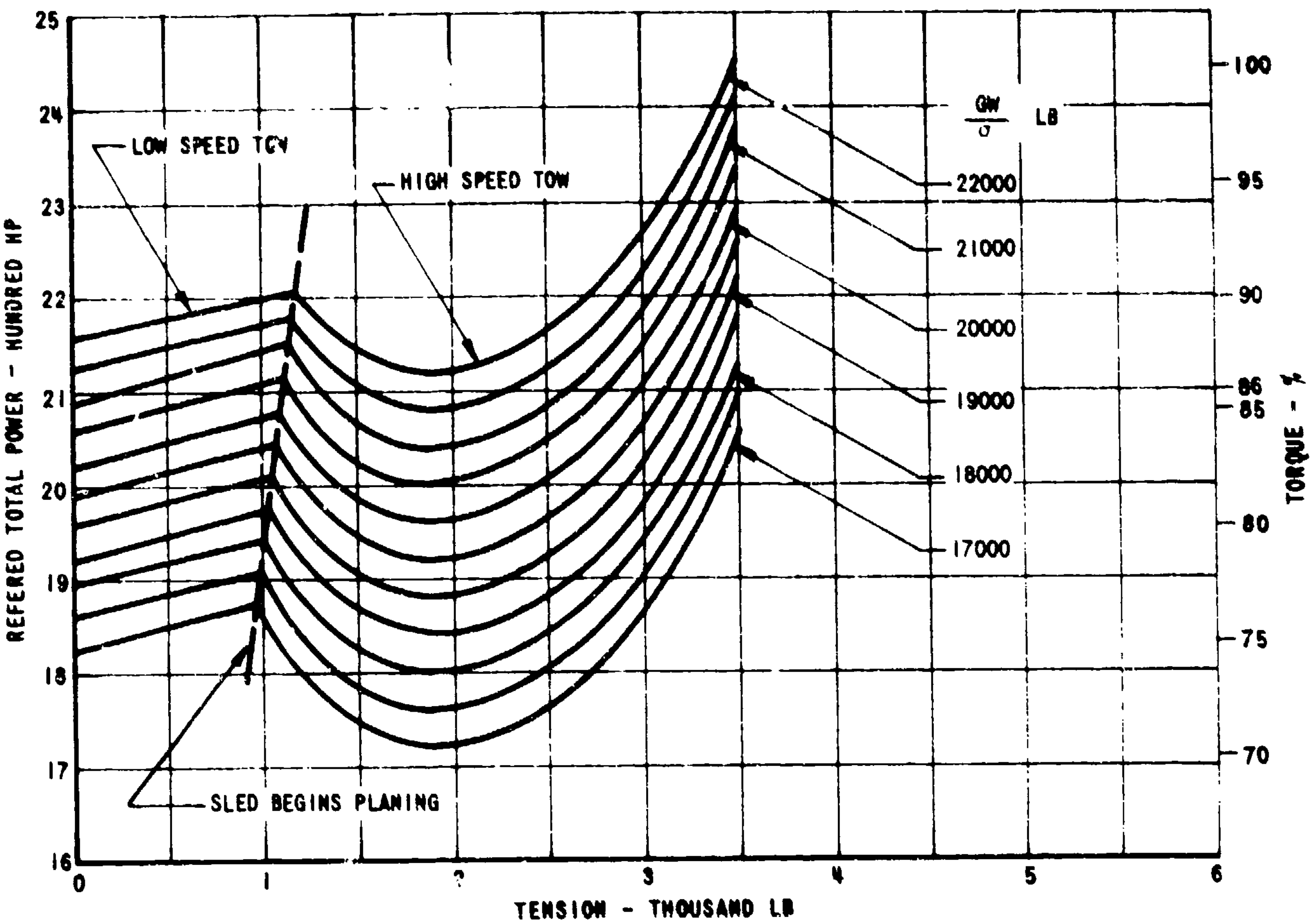

Figure E-10
HH-3F Helicopter
CG 1471
Tow Performance Sled

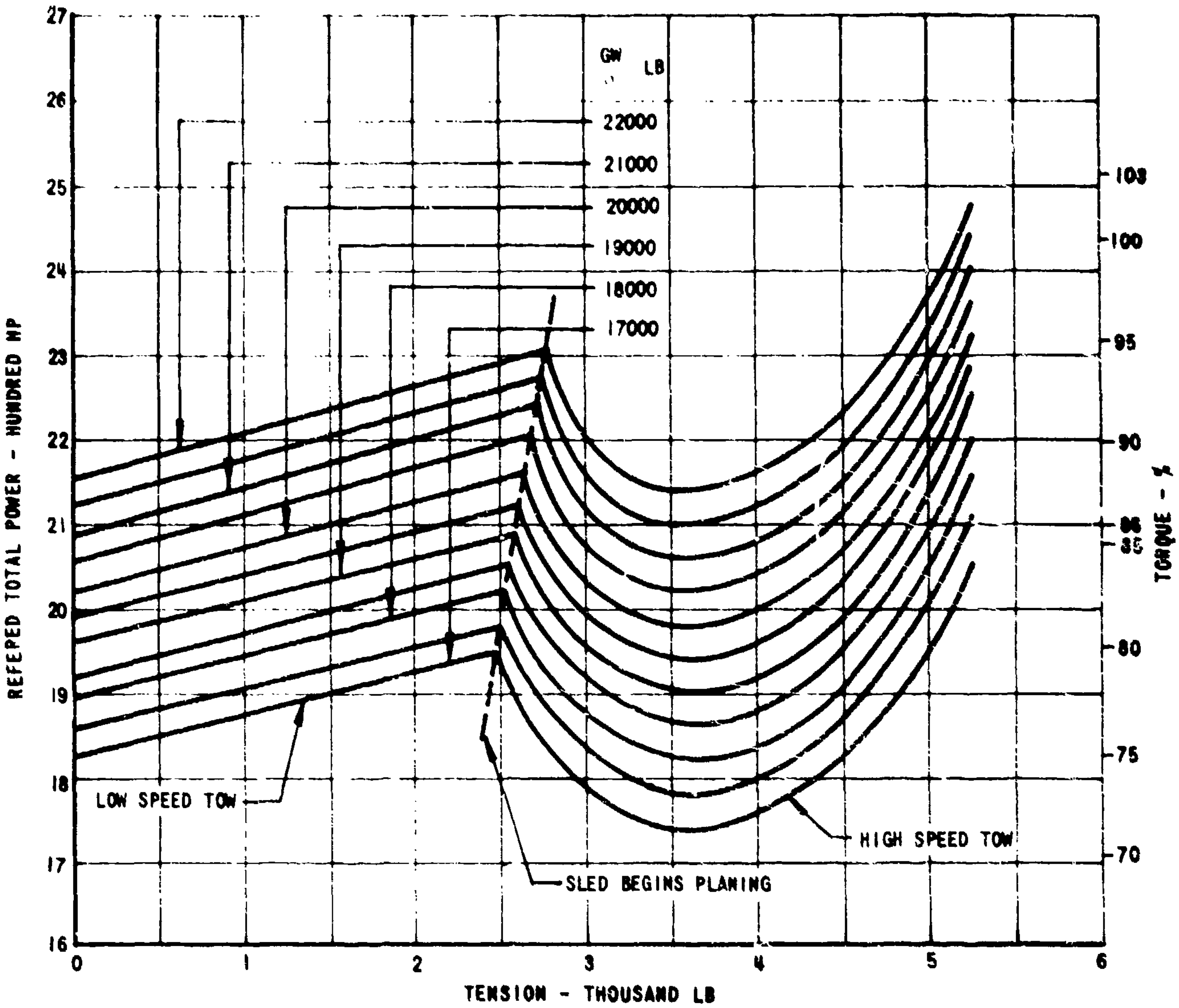

Figure E-11
HH-3F Helicopter
CG 1471
Tow Performance Sled and ADAPTS

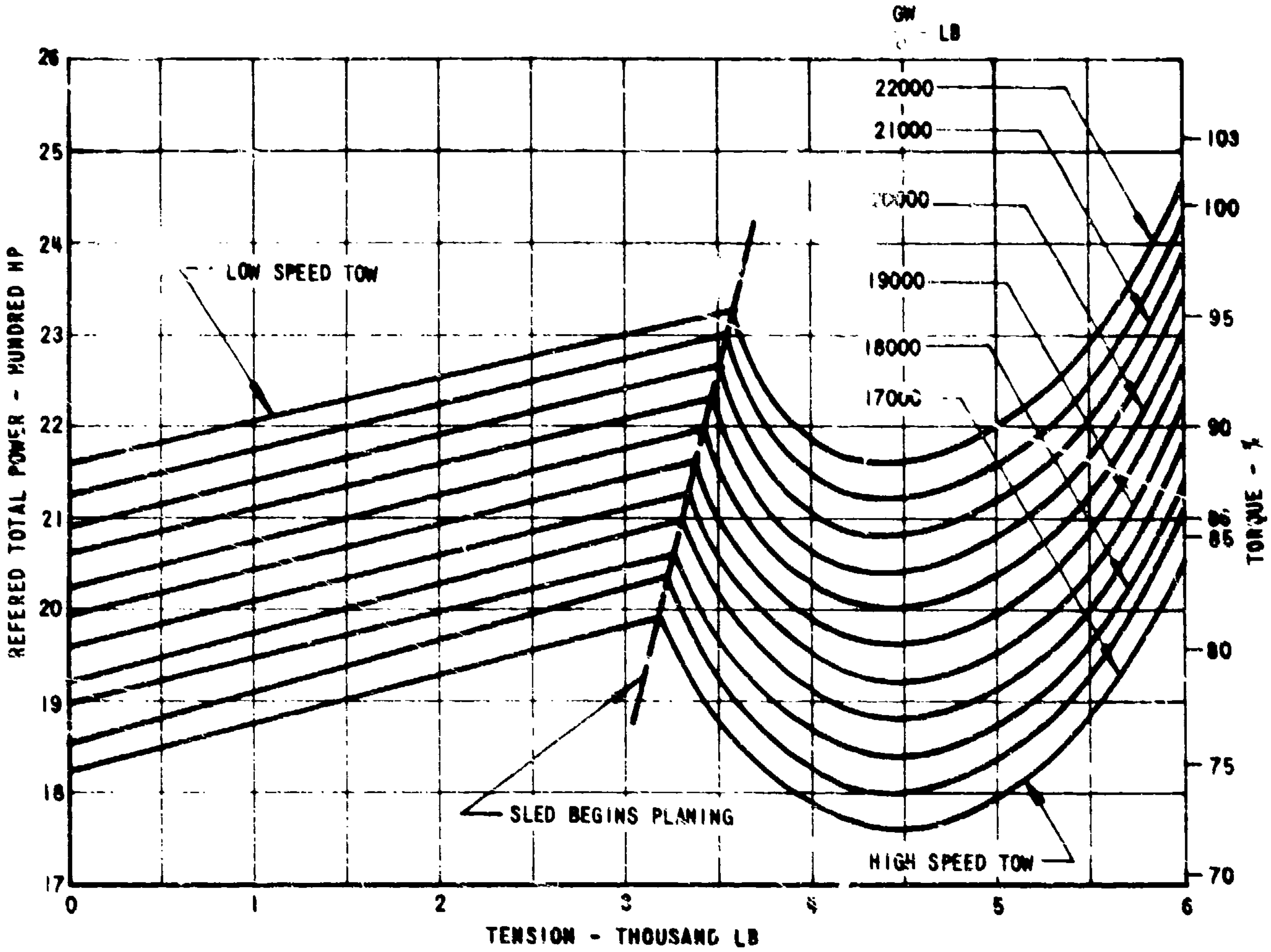

Figure E-12
HH-3F Helicopter
CG 1471
Tow Performance Sled and Barrier
Sled and Recovery Device

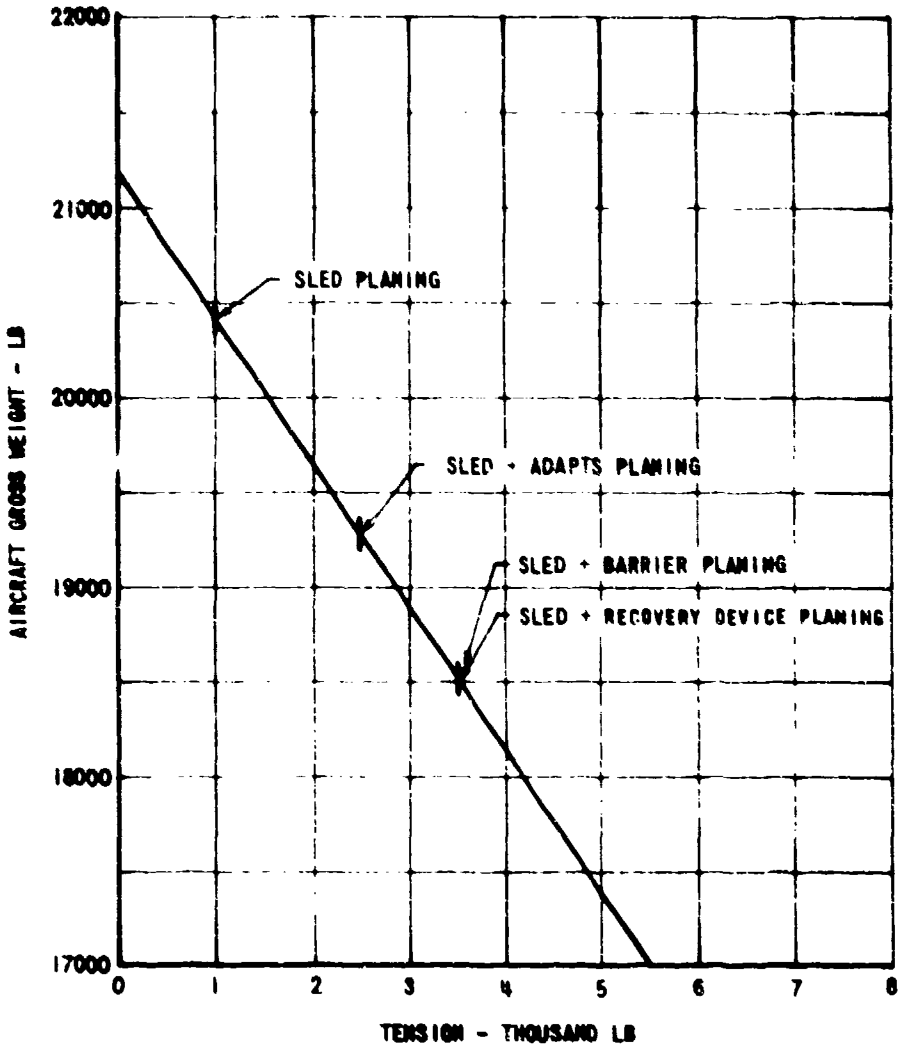

Figure E-13
HH-3F Helicopter
CG 1471
Maximum Low Speed Tow Performance

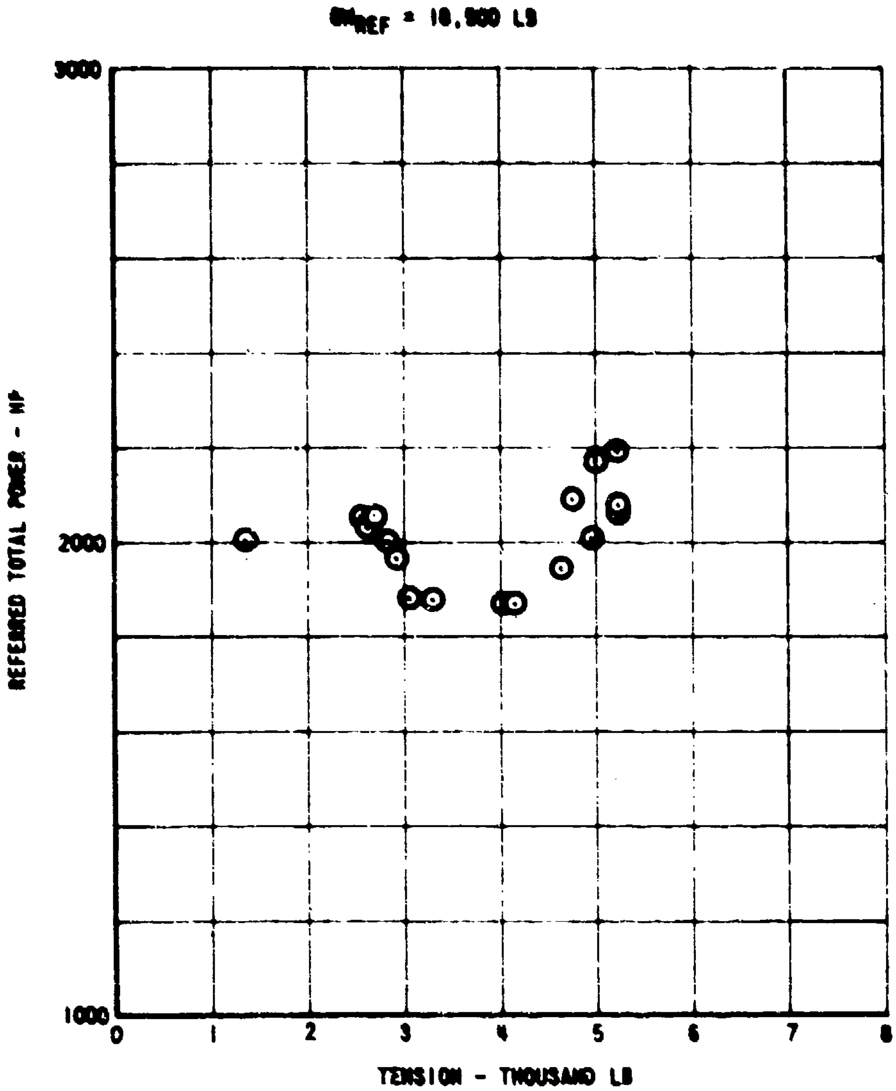

Figure E-14
HH-3F Helicopter
CG 1471
Tow Performance

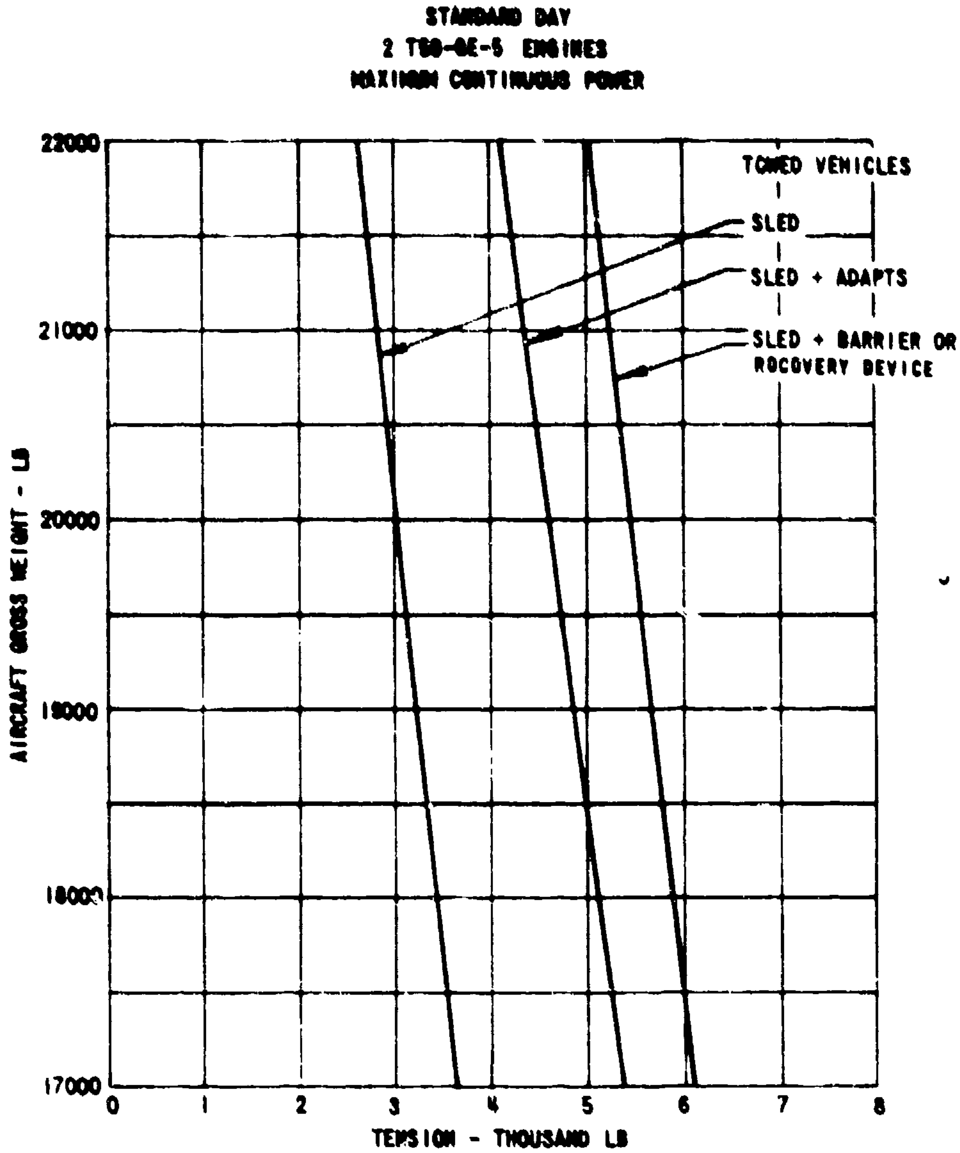

Figure E-15
HH-3F Helicopter
CG 1471
Maximum High-Speed Tow Capability

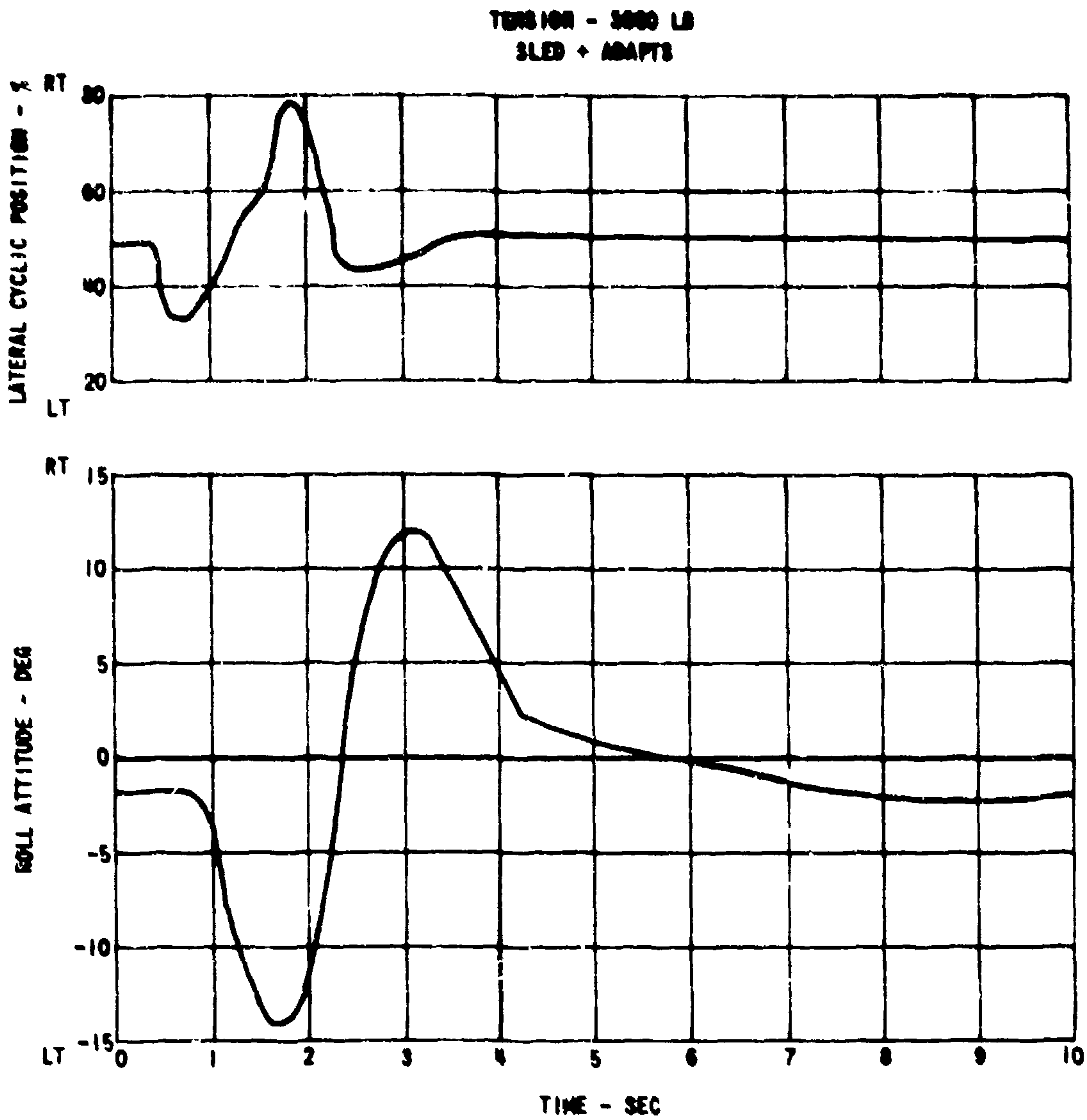

Figure E-16
HH-3F Helicopter
CG 1471
Lateral Cyclic Pulse

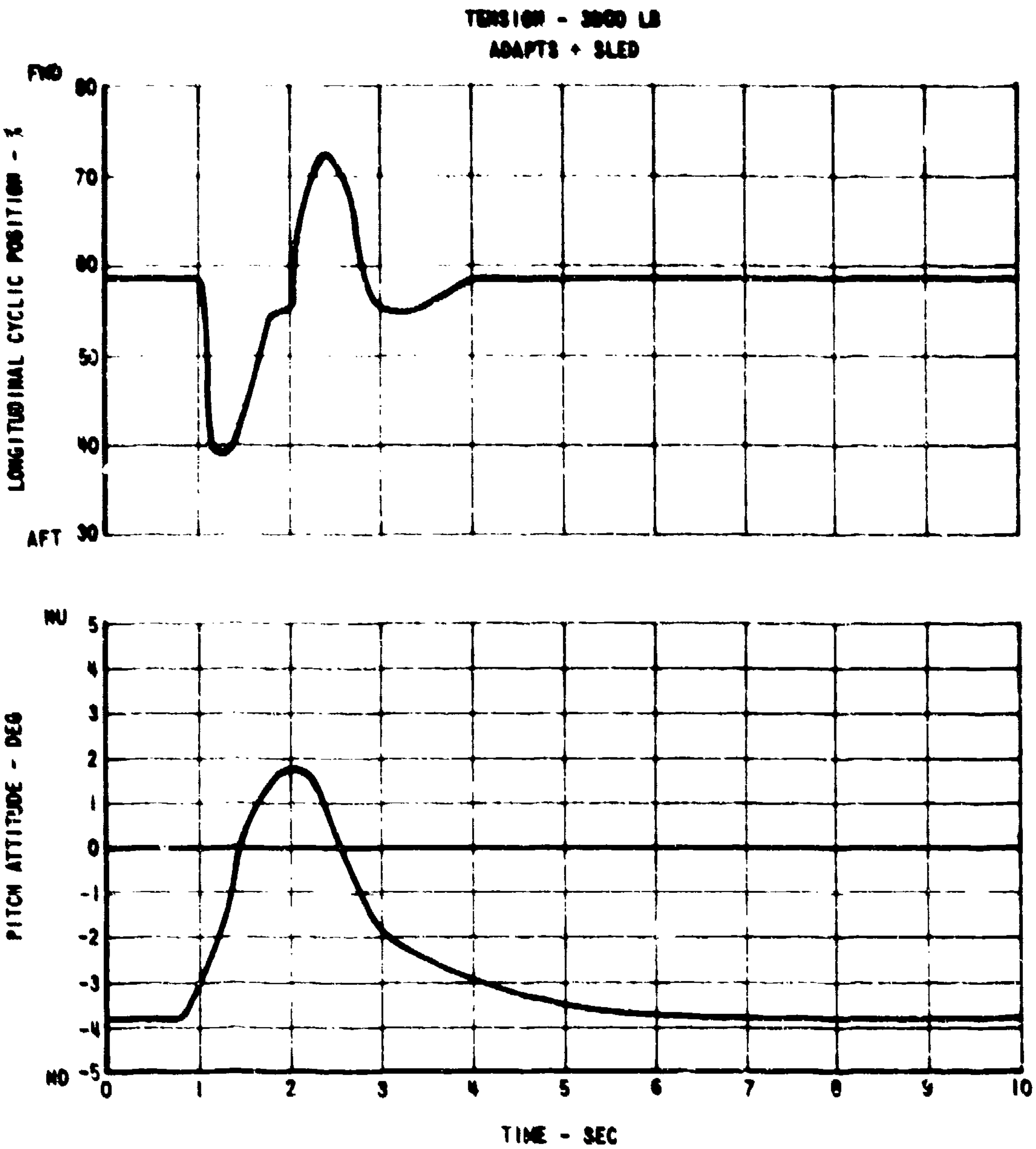

Figure E-17
HH-3F Helicopter
CG 1471
Longitudinal Cyclic Pulse

PERFORMANCE CALCULATIONS

Aircraft performance was calculated automatically for tests conducted at NAVAIRTESTCEN and manually by the project engineer for those tests conducted at NAVCOASTSYSLAB. In each case, the referred method shown in reference 13 was used. A summary of this method is presented below:

$$\text{Let } C_T = \frac{GW}{\pi R^2 \rho (\Omega R)^2} \tag{1}$$

$$\text{if } C_{TRef} = C_{T\,Test} \tag{2}$$

Then by substitution of equation (1) into equation (2)

$$\frac{GW\ Ref}{\pi R^2 \rho\ ref\ (\Omega R)^2\ ref} = \frac{GW\ Test}{\pi R^2 \rho\,test\ (\Omega R)^2\ test} \tag{3}$$

Solving equation (3) for GW_{Ref} gives:

$$GW_{Ref} = \frac{GW\ Test}{\rho test/\rho ref} \frac{(\Omega R)^2\ ref}{(\Omega R)^2\ test} \tag{4}$$

$$\rho test/\rho ref = \sigma \tag{5}$$

Substituting equation (5) into equation (4) gives:

$$GW_{Ref} = \frac{GW}{\sigma\ Test} \frac{(\Omega R)^2\ Ref}{(\Omega R)^2\ Test} \tag{6}$$

$$\text{Let } C_p = \frac{TP}{\pi R^2 \rho (\Omega R)^3} \quad \text{where } TP = MRSHP + TRSHP + 90$$

By repeating the above sequence we have for TP_{Ref}

$$TP_{Ref} = \frac{TP}{\sigma\ Test} \frac{(\Omega R)^3\ Ref}{(\Omega R)^3\ Test}$$

where:
- C_T - Thrust Coefficient
- C_p - Power Coefficient
- GW - Aircraft Gross Weight [Pounds]
- ρ - Air Density $\left[\frac{\text{Pound Second}^2}{\text{Feet}^4}\right]$
- R - Main Rotor Radians [Feet]
- Ω - Main Rotor Rotational Velocity [Radians/Second]
- TP - Total Aircraft Power [Horsepower]
- Ref - Standard Day Referred Value
- Test - Test Day Value

TOW OPERATING PROCEDURES

TOW OPERATING PROCEDURES

The following information should be incorporated in the HH-3F Flight Manual T. O. 1H-3(H)F-1:

SECTION II

TOW OPERATIONS

The mechanical and electrical operation of the tow system is explained in detail in Section IV.

PREFLIGHT

Planning. Complete both a weight-and-balance form and a takeoff-and-landing (TOLD) card prior to attempting the flight. Review the tow envelope for the assigned mission. Define crew member responsibilities in case of aircraft emergencies.

NOTE

Tow operations are confined to day, Visual Meterological Conditions only.

Equipment Inspection. The following items should be inspected prior to tow operations:

1. Tow boom and attachments for security.

2. Tow cable and reel for proper stowage.

3. Quick release hook checked to release electrically and manually and hook free of dirt, grease, etc.

4. Aft ramp cable extensions rigged.

5. Tow boom electrical fittings attached to cabin fittings.

INFLIGHT

CAUTION

Tow operations should be terminated if electrical storms are in the vicinity.

1. Equipment preparation.

   a. Tow cable attached to quick release hook.

   b. Aft ramp open to horizontal position and ramp power secured.

   c. Tow crewman's gunner belt attached lifeline. Assisting crewman positioned forward of tow boom.

   d. Pilot's HOT MIC LISTEN - ON.

2. Approach and hookup.

   a. Pilot complete approach to an altitude coupled hover downwind of the FSD sled. Maintain a minimum hover altitude of 40 feet in order to minimize salt spray.

   b. Tow crewman position himself on the aft ramp assisting aircrewman positioned forward of the tow boom.

   c. Prior to moving over sled, payout cable to within 10-15 feet of the surface.

   d. Pilot commence moving over sled; tow crewman direct pilot into position over sled using standard hoist procedures.

   e. Tow crewman monitor hookup; report when personnel are clear of sled.

   f. Pilot slowly moves forward and climbs to a minimum 75-foot hover assisting aircrewman pays out cable.

   g. When sled is visible from tow boom, tow crewman move to tow station which is on the starboard side, forward of the tow boom.

   h. Ramp power given to aft station; lower aft ramp to full cable extension.

   i. Continue moving forward until entire cable is deployed. At this time, assisting aircrewman move forward and strap into his normal crew position.

3. Tension takeup.

   a. When all tow cable has been deployed, the pilot will slowly takeup the cable slack.

   b. Tow crewman will advise of the initial skew angles until sufficient tension is placed on the system for cockpit indications to become reliable.

c. Skew angle corrections can be made using rudder pedals or the yaw trim knob. If skew is right, left pedal is applied, thus moving the ramp opening to the right and centering the tow cable and vice versa.

d. Tensions required for the FSD sled to attain planing are dependent on sled loads and configuration.

e. Attempting to takeup tension too rapidly may result in surging. To correct for surging in the sled and tow cable, utilize surging techniques as outlined in paragraph 4.d.

4. Tow flight.

NOTE

A cg trim adjustment should be made shortly after tension is indicated to provide adequate longitudinal trim authority.

a. Turns are accomplished by placing the cyclic into the direction of turn and maintaining zero skew angle by rudders. Constant tension should be held through all turns.

b. Helicopter attitudes of 4 to 8 degrees nose-down are common, dependent on tow speed and tension desired.

c. Tow operations shall not be conducted without a fully operational AFCS and altitude coupler.

d. Surging or tow cable oscillations are reduced by towing at the published optimum tow tension. If surging occurs, apply aft cyclic until surging ceases and then return cyclic to the original tow trim position.

e. The tow crewman has continuous ramp power at the aft station as long as no personnel are on the ramp. The crewman has ramp power in order to close the aft ramp in case of an emergency.

f. The helicopter power margin will be small during hookup and tension take-up maneuvers. When the FSD sled commences planing and the helicopter passes through translational lift, the power requirements decrease noticeably and will normally be under the maximum continuous power limitations (review engine power limits concerning time versus power).

g. Tow altitudes may range from 75-100 feet. Seventy-five feet has been determined to be the minimum safe altitude for recovery of the helicopter in the event of a single-engine failure. Higher altitudes, up to 100 feet, may be used as long as cable-to-ramp contact does not occur.

5. Tow release.

   a. For normal tow release, slow the helicopter and establish a stable hover. When FSD sled stabilizes dead in the water, assist personnel will go aboard and disconnect tow cable. Reel in cable, secure aft ramp, and complete mission.

   b. An aircraft emergency or uncontrollable sled may require immediate cable release which can be accomplished by either the cockpit electrical release or the cabin manual release.

CAUTION

Ramp power will be secured any time personnel are proceeding onto the aft ramp for hookup or release procedures.

TAIL ROTOR DRIVE SYSTEM FAILURE UNDER TOW

Symptoms:

1. Excessive vibration or noise in the tail section.
2. Aircraft commences yaw sharply to the right.
3. Tail rotor pedals movable but with no apparent effect.

Corrective Action.

1. Collective - reduce to descend and retard helicopter rotation.

CAUTION

Do not release tow load.

2. Cyclic - reduce speed and level helicopter.
3. Wheels - down/up over water.
4. Crew - alerted.
5. IFF - emergency.
6. Distress call - transmit.
7. Spee selectors - shut off at 10 feet altitude.
8. Collective - cushion landing.
9. Perform engine shutdown procedures.

SINGLE-ENGINE FAILURE UNDER TOW

WARNING

Pilot response to single-engine failure is dictated by gross weight, ambient conditions, relative wind, and height above the water. These factors will determine whether a flyaway recovery or water landing should be attempted. Relative wind effects will change considerably following a turn and flyaway capability should be recomputed after each turn.

CAUTION

An emergency water landing with the aft ramp in the locked down tow position may result in a pitch down moment as the ramp affords hydrodynamic braking. Excessive use of aft longitudinal cyclic to compensate for this moment could result in main rotor blade to tail pylon contact.

1. Landback.

   a. Aircraft attitude - position nose to obtain ground speed desired for touchdown.

   b. Collective - adjust as necessary and release coupler.

   c. Release tow cable.

   d. Raise lower ramp.

   e. Assume landing attitude at sufficient altitude to provide adequate tail clearance.

   f. Collective - cushion landing as necessary.

2. Continued flight.

   a. Collective - adjust for maximum power while maintaining N_r.

   b. Release coupler.

   c. Release tow cable.

   d. If necessary, smoothly lower the nose to exchange altitude for airspeed.

   e. Speed Selectors - recheck full forward.

   f. Accelerate to 70 KIAS and transition to 80 KIAS climb attitude.

   g. Analyze all engine instruments.

TOW EQUIPMENT DESCRIPTION

TOW BOOM

The tow system for the HH-3F was designed in conjunction with the FSD system. All components of the tow system are designed in order that installation can be accomplished by a two-man team. Components of the system consist of a tow boom with quick release hook, cable and reel, and associated fittings for attachment to the helicopter. Helicopters modified by TCTO * ____________ have attachment fittings in the aft cabin to accept installation of the tow boom. Vertical motion of the boom will be contained by bungee cords attached to cabin overhead and deck fittings.

QUICK RELEASE HOOK

The quick release hook is located at the end of the tow boom and provides the attachment point for the tow cable. Integral sensing units permit the quick release hook to sense both tow tension and cable skew angle. From the quick release hook, tension and skew angle data are transmitted to the cockpit for display on the pilot's and copilot's skew angle and tensiometer instruments. The skew angle and tensiometer instruments operate on the primary bus and are protected by circuit breakers marked TOW INST. overhead the pilot and copilot. The tow cable can be released at the quick release hook electrically, manually, or automatically. Electrical release of the cable is accomplished in the cockpit utilizing the TOW REL switch. The circuitry for the cable electrical release is on the DC primary bus and is protected by the TOW REL circuit breaker located on the center overhead circuit breaker panel. Manual release of the tow cable is conducted by using the release handle located on the forward portion of the tow boom and starboard side of the cabin. The quick release hook will automatically release the tow cable when tow tension attains 12,000 pounds of force.

TOW CABLE

The tow cable is 600 feet in length and is stored on a lightweight portable cable reel. The cable has a rated tensile strength of 38,000 pounds. In the helicopter, the cable and reel are located forward of the tow boom and attached to cabin deck fittings with troopseat-type lugs. The cable must be manually pulled for removal from the reel. The cable may be restored on the reel by use of the electrical winch driving the reel or manually rolling the reel. The cable reel electrical winch receives its power from the primary bus and is protected by the TOW WINCH circuit breaker overhead the * ____________.

SUPPLEMENTARY TOW EQUIPMENT

Ramp cable extensions are provided to allow the aft ramp to be lowered below horizontal. The added extension allows an increased clearance for the tow cable in order to preclude tow cable to ramp contact during tow operations. In the aft cabin along the port side, a 10-foot cable has been attached fore and aft which provides the crewman with a gunner's belt attaching point. Attachment to the fixed cable allows freedom of movement on the aft ramp for the crewman during tow cable hookup and recovery evolutions.

(Diagram of the TOW BOOM and CABLE REEL inside the cabin, similar to cargo sling in figure 4-12 of the HH-3F Flight Manual)

*Will be determined at a later date by the U. S. Coast Guard

GLOSSARY OF TERMS

Doublet Input	-	A control movement of equal magnitude on both sides of trim, terminating at the original trim position.
Dynamic Tow	-	The act of pulling a movable object.
High-Speed Tow	-	Dynamic tow with the sled planing.
Low-Speed Tow	-	Dynamic tow prior to sled planing.
Pulse Inputs	-	Control input by which the control is displaced from trim a specific distance for a specific period of time, then returned to trim.
Skew Angle	-	That angle described by the tow cable and the centerline plane of the aircraft measured at the hook pivot.
Skewmeter	-	Skew angle readout in the cockpit.
Static Tow	-	The act of pulling against an immovable object.
Tensiometer	-	Tow cable tension readout in the cockpit.
Tow Cruise	-	The tow tension corresponding to the tension which results in the least power required to tow.

REFERENCES

1. Military Interdepartmental Procurement Request Z-70099-5-51502 of 16 Dec 1974.

2. NAVAIRTESTCEN Report of Test Results FT-12R-75, HH-3F Helicopter Tow Capability Development, First Interim Report of 20 Feb 1975.

3. NAVAIRTESTCEN Report of Test Results FT-30R-75, Second Interim Report of 27 Mar 1975.

4. NAVAIRTESTCEN Report of Test Results RW-5R-75, Third Interim Report of 16 Apr 1975.

5. NAVAIRTESTCEN Report of Test Results RW-13R-75, Fourth Interim Report of 14 May 1975.

6. NAVAIRTESTCEN Report of Test Results RW-19R-75, Fifth Interim Report of 11 Jul 1975.

7. NAVAIRTESTCEN Report of Test Results RW-37R-75, Sixth Interim Report of 16 Oct 1975.

8. NAVCOASTSYSLAB msg 021840Z Oct 1975.

9. U. S. Coast Guard Model HH-3F Helicopter Flight Manual T. O. 1H-3(II)F-1 of 1 Aug 1974.

10. NAVCOASTSYSLAB Report, Helo/Ship Towed Planing Hull Sled for Fast Surface Delivery of High Seas Oil Pollution Control Equipment of Feb 1975.

11. NASA Technical Note NASA TN-D-5153, The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities of Apr 1969.

12. MIL-B-5087B, Bonding, Electrical, Lightning Protection for Aerospace Systems of 15 Oct 1964.

13. USNTPS-FTM-No. 102, Helicopter Performance of Jun 1968.